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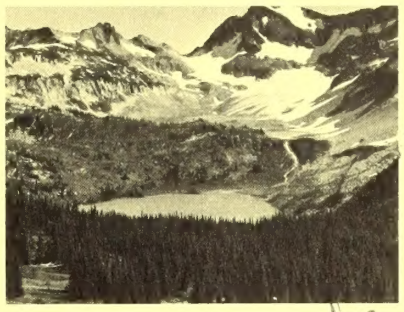
VEGETATION OF OREGON & WASHINGTON

by Jerry F. Franklin and C.T. Dyrness



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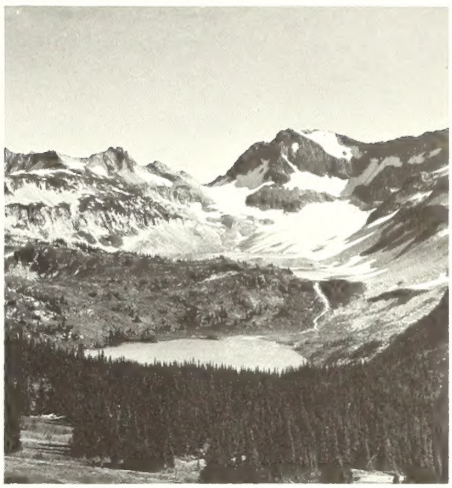

VEGETATION OF OREGON AND WASHINGTON

by
Jerry F. Franklin and C. T. Dyrness
Pacific Northwest Forest and Range Experiment Station
U. S. Department of Agriculture, Portland, Oregon

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INTRODUCTION

The Pacific Northwest is among the more diverse regions of North America in environment and vegetation. Oregon and Washington, the heart of this region, encompass wet coastal and dry interior mountain ranges, miles of coastline, interior valleys and basins, and high desert plateau (fig. 1). Moisture, temperature, and substrate vary greatly. Natural vegetation types range from dense coastal forests of towering conifers through woodland and savanna to shrub steppe.

The ecology and plant geography of the region have been studied by scientists for over half a century. Major contributors have included W. S. Cooper, R. Daubenmire, H. P. Hansen, L. A. Isaac, V. J. Krajina, D. B. Lawrence, T. T. Munger, M. E. Peck, C. V. Piper, E. H. Reid, and G. B. Rigg. Unfortunately, most of the knowledge which has been gathered is fragmented — dispersed through journals, books, theses, and unpublished files of data.

We present here a generalized account of the major vegetation types within the States of Oregon and Washington, an integration of the scattered information into a regional account. Published articles, theses, and personal data files are the source materials. The unevenness of coverage is unfortunate but unavoidable; some plant formations have been studied in great detail, and other communities or locales have received cursory or no study.

The purpose is threefold: (1) to outline major phytogeographic units and suggest how they fit together and relate to environmental factors; (2) to direct the interested reader to sources of detailed information on the environment and vegetation of the Pacific Northwest, since such information cannot be provided in an account of this size; and (3) to illustrate the major plant communities with photographs.

We hope this outline will enable the scientist or student new to the Pacific Northwest to better understand what he is seeing and how his various observations are related. Perhaps it will also provide some new insights to readers more familiar with the region.

DEFINITIONS

Ecology is fraught with specialized and ambiguous terminology. We have followed Daubenmire's (1968a)[1] definitions in most cases, especially when dealing with synecological terminology, such as climax, association, etc. The reader unfamiliar with such terms might particularly consider pages 27 to 32, 229 to 237, and 259 to 262 of this text for orientation. The glossaries of Carpenter (1956), Hanson (1962), and Habeck and Hartley (1968) are also helpful.

NOMENCLATURE

Plant nomenclature in this paper generally follows these sources: trees, Little (1953); other vascular plants, Hitchcock et al. (1955, 1959, 1961, 1964) or Peck (1961) for taxa not covered in the former; mosses, Lawton (1965); and lichens, Howard (1950). Whenever possible, nomenclature from older ecological studies cited has been updated. In an appendix are listed the complete scientific names for taxa mentioned along with common names locally applied to many of the plants.

PALEOBOTANY, PALEOECOLOGY, AND FLORISTIC EVOLUTION

The evolution of the flora and plant formations of Oregon and Washington is not within the scope of this paper. We recommend readers interested in these subjects consult the following: Chaney (1938, 1948) and Axelrod (1958) on paleobotany, Hansen (1947) and Heusser (1960) on postglacial vegetation changes and development, and Daubenmire (1947), Mason (1947), and Detling (1968) on evolution of plant formations and floras.

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[1] Names and dates in parentheses refer to literature listed in References, beginning on p. 182.

123°
122°
121°
120°
119°
118°
117°
49°
48°
47°
46°
BELLINGHAM
MOUNT BAKER
ROSS LAKE
SKAGIT RIVER
SAUK RIVER
METHOW RIVER
OKANOGAN R.
OKANOGAN HIGHLANDS
PEND OREILLE R.
COLVILLE RIVER
SANPOIL R.
OKANOGAN
LAKE CHELAN
GLACIER PEAK
SOLEDUCK RIVER
ELWHA R.
PORT ANGELES
HOH RIVER
QUEETS R.
QUINAULT RIVER
OLYMPIC MOUNTAINS
PUGET SOUND
EVERETT
SKYKOMISH R.
SNOQUALMIE R.
SEATTLE
CASCADE RANGE
WENATCHEE RIVER
COLUMBIA R.
SPOKANE R.
SPOKANE
WENATCHEE
TACOMA
ABERDEEN
GRAYS HARBOR
OLYMPIA
CHEHALIS RIVER
NISQUALLY R.
MOUNT RAINIER
ELLENSBURG
NACHES RIVER
YAKIMA RIVER
PALOUSE RIVER
PULLMAN
WILLAPA BAY
CHEHALIS
COWLITZ RIVER
YAKIMA
SNAKE RIVER
ASTORIA
KELSO
MOUNT ST. HELENS
MOUNT ADAMS
PASCO
WALLA WALLA
NEHALEM R.
WILSON R
COLUMBIA RIVER
COLUMBIA RIVER GORGE
OCEAN

Figure 1. — Major topographic features and some cities and towns in Oregon and Washington.

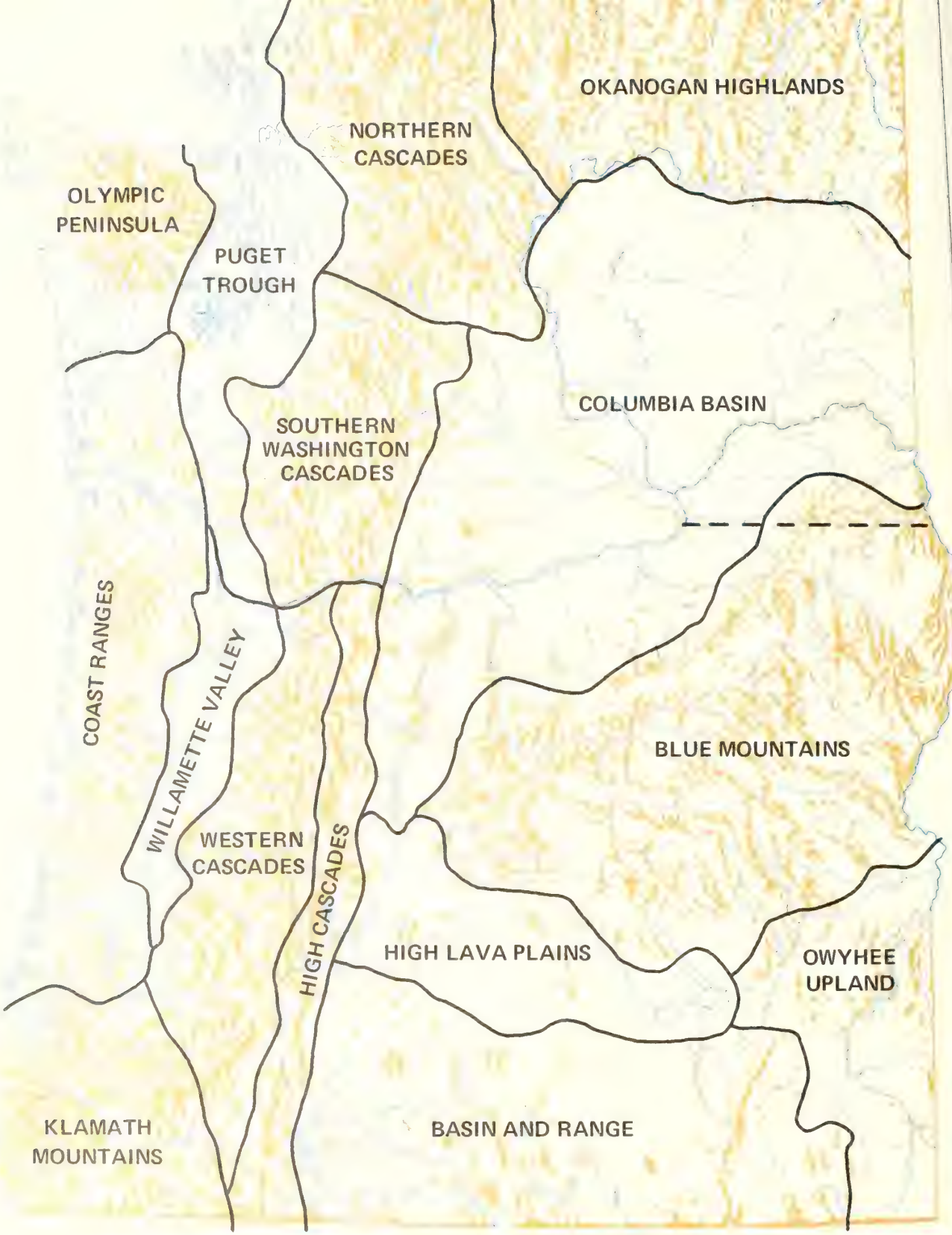


Figure 2. — Physiographic and geological provinces of Oregon and Washington.

ENVIRONMENTAL SETTING

PHYSIOGRAPHY, GEOLOGY, AND SOILS

Since geology, physiography, and at least some aspects of soils are interrelated, we will consider these three environmental features together. In Oregon and Washington, all three present highly varied and complex patterns. Landforms vary from level river valleys and lava plains to precipitous mountain slopes. Elevations range from sea level to over 4,450 meters. The geologic complexity is bewildering in many areas with formations dating from the Paleozoic era (over 400 million years old) to Recent. Vulcanism has dominated the shaping of much of the landscape, but sedimentary and metamorphic rocks also abound.

Since climate and vegetation are added to landform and geology as factors in soil formation, the tremendous variety of soils is not surprising. For example, zonal great soil groups range from Desert soils in arid southeastern Oregon to Podzol soils in the cool, humid climate of the northern Cascade Range. The most striking soil changes within short distances are found on eastern slopes of the Cascade Range. Here Podzol and Chestnut soils are separated by only a few kilometers because of abrupt changes in precipitation and concomitant changes from forest to grass-shrub vegetation.

The great relief in extensive mountainous areas within Oregon and Washington perpetuates many soils in a state of profile immaturity. Soils on steep slopes are constantly influenced by gravitational instability expressed as soil creep or landslides, often severely limiting profile development. Consequently, many mountain soils are Regosols or Lithosols lacking genetic horizons, except for a thin A. In these areas, effects of the parent rock on soil properties are major and those of climate and vegetation are minimal. Areas of these azonal soils are typically characterized by extensive rock outcroppings.

Volcanic activity along the crest of the Cascade Range during Pleistocene and Recent times has extensively influenced regional soils. Large tracts at higher elevations in the Cascades are mantled with deposits of pumice and volcanic ash which, because of their youth, generally exhibit little genetic development. In many areas, such as the southern Cascade Range of Washington, there have been several depositions of volcanic ejecta; soil profiles often have three or four buried horizon sequences.

Pumice and volcanic ash soils also occur well beyond the Cascade Range. Distance from their source and orientation of these deposits are largely functions of wind direction and velocity during eruptions. Recently, it has become apparent that many, if not most, of the soils of the Pacific Northwest have had some influence from aerially deposited volcanic ejecta. Amounts of incorporated ash and pumice are often small, however, and detectable only through detailed soil mineralogic or micromorphological investigations.

For descriptive purposes, the two-State area has been separated into 15 physiographic provinces (fig. 2). The divisions used are largely those outlined by Baldwin (1964) and Fenneman (1931). Naturally, in many instances, boundaries separating provinces are arbitrary and gradual transitions exist. However, the provinces are broad stratifications of relatively homogenous areas and reduce complexity to more manageable proportions.

Geologic information for this section is from several primary sources: for Oregon, Baldwin (1964) and "Geologic Map of Western Oregon West of the 121st Meridian" (Wells and Peck 1961); for Washington, Campbell (1953) and "Geologic Map of Washington" (Huntting et al. 1961). Other pertinent references included Williams (1942), Danner (1955), Foster (1960), Snavely and Wagner (1963), Fiske, Hopson, and Waters

(1963), Peck, Griggs, Schlicker et al. (1964), and Mackin and Cary (1965).

Soils information, particularly naming and distribution of great soil groups, is based largely on "Soils of the Western United States" (Western Land Grant Universities et al. 1964). Other references consulted include Knox (1962), Youngberg (1963), and numerous soil survey reports for localized areas.

Table 1 shows the relative importance of various great soil groups within the 15 physiographic provinces.

Table 1. — Principal great soil groups within the 15 physiographic provinces of Oregon and Washington

Province	Widespread great soil groups[1]	Less abundant great soil groups
Olympic Peninsula	Sols Bruns Acides Reddish Brown Lateritic Lithosol	Podzol Brown Podzolic Alpine Turf Alpine Meadow Humic Gley Alluvial Regosol Rockland[2]
Coast Ranges	Reddish Brown Lateritic Sols Bruns Acides Regosol Lithosol	Noncalcic Brown Prairie Grumusol Humic Gley Alluvial
Klamath Mountains	Reddish Brown Lateritic	Sols Bruns Acides Noncalcic Brown Western Brown Forest Podzol Prairie Grumusol Humic Gley Alluvial Lithosol Rockland[2]
Willamette Valley	Prairie Planosol Alluvial	Gray-Brown Podzolic Chernozem Reddish Brown Lateritic Grumusol Humic Gley
Puget Trough	Brown Podzolic Regosol Alluvial Reddish Brown Lateritic	Gray Wooded Prairie Sols Bruns Acides Humic Gley Lithosol
Northern Cascades	Podzol Brown Podzolic Lithosol	Western Brown Forest Gray Wooded Chestnut Alpine Turf Alpine Meadow Regosol Rockland[2]
Southern Washington Cascades	Brown Podzolic Podzol Lithosol Regosol	Reddish Brown Lateritic Gray-Brown Podzolic Sols Bruns Acides Western Brown Forest Chestnut Humic Gley Alluvial Rockland[2]

Table 1. — Continued

Province	Widespread great soil groups[1]	Less abundant great soil groups
Western Cascades	Brown Podzolic Regosol Reddish Brown Lateritic	Podzol Sols Bruns Acides Noncalcic Brown Prairie Humic Gley Alluvial Lithosol Rockland[2]
High Cascades	Regosol Brown Podzolic	Podzol Western Brown Forest Lithosol Rockland[2]
Okanogan Highlands	Brown Podzolic Gray Wooded Lithosol	Western Brown Forest Chernozem Brown Humic Gley Alluvial Regosol Rockland[2]
Blue Mountains	Western Brown Forest Regosol Lithosol	Brown Podzolic Reddish Brown Lateritic Chernozem Chestnut Prairie Alpine Turf Alpine Meadow Humic Gley Alluvial Rockland[2]
Columbia Basin	Brown Chestnut Chernozem Prairie Sierozem Regosol	Planosol Humic Gley Solonetz Solonchak Alluvial Lithosol Rockland[2]
High Lava Plains	Brown Chestnut Lithosol Regosol (pumice)	Solonetz Solonchak Humic Gley Alluvial Regosol Rockland[2]
Basin and Range	Brown Chestnut Lithosol Regosol (pumice) Western Brown Forest	Chernozem Prairie Reddish Brown Lateritic Sierozem Desert Humic Gley Solonetz Solonchak Alluvial Regosol Rockland[2]
Owyhee Upland	Brown Chestnut Lithosol	Sierozem Desert Solonetz Humic Gley Alluvial Regosol Rockland[2]

[1] Listed in approximate order of importance.
[2] A miscellaneous land type in which rock outcrops or rock rubble dominate the landscape.

Figure 3. — **The rugged Olympic Mountains viewed from Hurricane Ridge (south of Port Angeles, Washington); the glacially carved valley contains the Elwha River (*photo courtesy of Olympic National Park*).**

Olympic Peninsula Province

The Olympic Peninsula province is made up of a central core of the rugged Olympic Mountains surrounded by almost level lowlands. On the east, the lowland strip is 3 to 16 kilometers wide and is part of the Puget Trough. The lowland strips are very narrow on the north, but 16 to 32 kilometers wide on the west, and 48 kilometers wide along the south side of the peninsula. Most ridges in the Olympic Mountains are 1,200 to 1,500 meters in elevation with some higher peaks attaining elevations of 2,100 to 2,420 meters. Glaciation has strongly influenced landforms. All main river valleys are broad and U-shaped, and all major peaks are ringed with cirques, many containing active glaciers. The extremely high precipitation (perhaps as high as 6,350 millimeters per year in the interior) has caused rapid down-cutting by streams, resulting in many precipitous mountain slopes (fig. 3).

Geologically, the mountainous portion of the Olympic Peninsula province is made up of two volcanic belts encircling a large interior area containing sedimentary rocks. The volcanic belts bound the peninsula on the north and east sides, and as far west as Lake Quinault on the south. The outer belt, by far the thickest, is comprised of basalt flows and breccias of Eocene age. Between the two vol-

canic belts lies a generally thin band of argillite and graywacke, also Eocene. The inner volcanic belt is very thin and discontinuous and consists of altered basalt, "pillow" lava, and flow breccia deposited late in the Mesozoic era or perhaps during the Paleocene epoch. The rugged interior of the peninsula is almost exclusively comprised of sedimentary rocks deposited late in the Mesozoic or very early in the Tertiary period. These rocks are largely graywacke, with some interbedded slate, argillite, and volcanic rocks.

The less mountainous area along the north edge of the peninsula is a complex of Oligocene and Miocene sandstones, some interbedded with siltstone and conglomerates. In addition, glacial drift occurs in fairly large deposits near Sequim and Port Angeles and west of Ozette Lake. The broad, level areas along the western and southern margins of the peninsula have been interpreted as marine terraces or glacial outwash fans.

Because of wide ranges in climate and parent materials, the soil pattern on the Olympic Peninsula province is unusually complex. Soils derived from basalt are uniformly reddish brown and moderately high in clay content. Depths vary from extremely shallow to deep. Soils from graywacke and sandstone are generally moderately shallow and stony, especially in the interior where steep topography greatly restricts profile development. Where moderate soil development has occurred, textures are most often loams to clay loams, and colors are generally brown. Large varieties of soils have formed in glacial till and outwash, depending on such factors as particle size and degree of compaction in parent materials. Fine-textured till often gives rise to poorly drained clay soils with high organic matter contents in surface layers. Well-drained soils derived from coarser till frequently have brown, loam-textured surface horizons underlain by a gravelly sandy clay subsoil.

The most common great soil groups[2] in the northeastern portion of the province are Podzols, Brown Podzolics, and Lithosols. Upland portions of more gentle terrain to the west and south are generally occupied by Reddish Brown Lateritic, Sols Bruns Acides, and Lithosolic soils. In low-lying areas and along major streams, the principal great soil groups are Alluvial and Humic Gley. Soils in the mountainous central core range from Podzols, Brown Podzolics, Lithosols, and Regosols at low to moderate elevations to Alpine Turf, Rockland, and Alpine Meadow soils at highest elevations.

[2] Great soil groups mentioned in the text are briefly described in the Appendix.

Coast Ranges Province

The Coast Ranges province extends from the middle fork of the Coquille River in Oregon northward into southwestern Washington where it includes the area known as the Willapa Hills. The entire southern section of the province is topographically mature — i.e., steep mountain slopes with ridges that are often extremely sharp (fig. 4). Excepting the area drained by the Wilson and Trask Rivers, the proportion of steep slopes decreases in the northern section of the Coast Ranges. Mountain passes are generally located on the eastern border of the range due to faster rates of headward erosion by the numerous westward-flowing streams. Elevations of main ridge summits in the province range from about 450 to 750 meters. Scattered peaks, often capped with intrusive igneous rocks, rise well above surrounding ridges. Marys Peak, 1,249 meters high, is the highest peak in the Coast Ranges.

Figure 4. — The Oregon Coast Ranges west of Eugene, Oregon; note accordant ridge crests and extensive stream dissection. The highest peak in the background is Roman Nose Mountain (elevation, 870 m.).

Geology south of the Salmon and Yamhill Rivers differs substantially from that to the north. Geologic history of the southern Coast Ranges began during early Eocene times with deposition of "pillow" basalts near the present town of Alsea. Later in the Eocene, the vast sedimentary beds of the Tyee formation, which make up by far the largest portion of this section of the Coast Ranges, were deposited under marine conditions. The Tyee formation, largely composed of rhythmically bedded, tuffaceous and micaceous sandstone, occurs throughout the southern Coast Ranges and is virtually the only rock present in the central portion. Also during the Eocene, other smaller marine sedimentary formations were laid down, mostly to the south and along the coast. Scattered igneous intrusions, largely gabbro, occurred during the Oligocene and cap many of the most prominent peaks (e.g., Marys Peak, Prairie Peak, and Grass Mountain). During the Miocene, localized depositions of both sedimentary and volcanic rocks occurred which are now exposed near Newport and Coos Bay. The Pliocene epoch saw no new depositions, the principal activity at this time apparently being the rapid erosion of the tremendously thick beds of sediments. Pleistocene deposits, generally sandy in nature, were laid down along the coast during a period of rising sea level. This general rise of sea level, following the melting of glacial ice, also drowned the mouths of coastal rivers.

As in the southern section, all rock formations in the northern Coast Ranges are Tertiary. Eocene formations are widespread and include both volcanic and sedimentary rocks. Eocene siltstone and sandstone are found along and to the south of the Yamhill River near Vernonia, Oregon, and in the Willapa Hills of southwestern Washington. Eocene volcanic rocks, largely basalt with some tuffs and breccias, occupy extensive areas northeast of Tillamook and in the Willapa Hills. Oligocene sedimentary formations, including siltstone, shale, and sandstone, are found near Vernonia, along the Nehalem River, and, to a limited extent, in the Willapa Hills. During the Miocene epoch, extensive basalt flows occurred in the most northerly section of the Oregon Coast Ranges and in the Willapa Hills. Near the Columbia River in Oregon, these flows are classified with the extremely widespread Columbia River Basalt. The Plio-Pleistocene was largely a period of erosion, with streams excavating their valleys as the ranges were slowly uplifted.

Soils developing in the very extensive deposits of sandstone exhibit a wide range of characteristics. On steep, smooth mountain slopes they tend to be shallow, stony, loam textured, and brown or yellowish brown. Soils derived from sandstone colluvium occupy uneven, benchy slopes that generally exhibit some degree of continuing instability. On broad ridgetops, soils tend to be deep, with some clay accumulation in the B horizon and, generally, a thick surface horizon of high organic matter content.

Soils developed from siltstone or shale parent materials resemble those derived from sandstone in some respects, but generally they are finer textured. Typically, they have a clay-textured B horizon and either a clay loam or clay surface horizon.

Soils from basalt are dark brown to reddish brown, and soil texture varies with soil depth; deeper soils are finer textured. On all parent materials, soils near the coast tend to have thicker, darker A horizons, indicating greater amounts of incorporated organic material.

The most common great soil groups in upland positions within the Coast Ranges province are Reddish Brown Lateritic, Sols Bruns Acides, Lithosol, and Regosol. In low-lying areas, principally along streams, soils are generally classified within the Humic Gley or Alluvial great soil groups. In the eastern foothills of the Coast Ranges, Noncalcic Brown, Prairie, and Grumusol soils are encountered.

Klamath Mountains Province

The Klamath Mountains province encompasses a complex of ranges in southwestern Oregon and northern California. The northernmost range in Oregon is commonly identified as the Siskiyou Mountains. This region is logically set apart from the remainder of southern Oregon by the boundary separating its pre-Tertiary rocks from Tertiary rock formations outside the area. The pre-Tertiary

rocks of this province probably include the oldest in Oregon.

The Klamath Mountains province is largely a region of rugged, deeply dissected terrain (fig. 5). Mountain crests, comprised of steeply folded and faulted pre-Tertiary strata, vary in elevation from 600 meters near the coast to approximately 1,200 meters in the east. Ridge accordance suggests an ancient and now greatly dissected peneplain. Many peaks rise above this summit peneplain. The highest of these monadnocks in Oregon is 2,280-meter Mount Ashland which rises 1,060 meters above the general level of its surroundings.

The geologic history of the Klamath Mountains began during the Paleozoic era with deposition of volcanic tuffs and sedimentary rocks which were subsequently metamorphosed, largely into schists. A period of erosion and folding followed until late in the Triassic period when a large series of volcanic and sedimentary rocks were deposited near Medford and Grants Pass. These rocks have all undergone extensive metamorphism into various types of schists, gneisses, marbles, and other metavolcanic or metasedimentary rocks. These rock types outcrop east of Gold Beach and at other scattered locations throughout the province. During the Jurassic period, sandstones, siltstones, and shales were laid down along the coast and in a belt extending from the southwestern corner of Oregon across the province in a generally northeasterly direction. Most of these deposits have undergone very little alteration. These rock strata were intruded with ultramafic rocks such as peridotite and dunite during late Jurassic or very early Cretaceous times. The intrusions have largely been altered to serpentine which now appears in elongated, stringerlike outcrops, generally associated with fault zones. Other rocks which were intruded at approximately the same time include a variety of granitics — diorite, quartz diorite, granodiorite, and granite. The largest areas of these rocks are found north and south of Grants Pass, east of Oregon Caves, south of Ashland, southwest of Tiller, and between Grants Pass and Gold Beach in the Pearsoll Peak area. The early Cretaceous period saw additional depositions of sediments — rocks which now appear as grayish-green arkosic sandstone and siltstone.

Figure 5. — The Klamath Mountains in Oregon showing characteristic, deep dissection and knifelike ridges.

Rock strata within the province were greatly modified by folding and deformation during the middle Cretaceous period. Apparently, the Klamath Mountains were truncated and underwent peneplanation during the Miocene and Pliocene epochs. Subsequent erosion and stream dissection have given rise to the mature topography which characterizes the area today.

The highly variable soil pattern follows the complex geology of the Klamath Mountains. The most widely distributed parent materials are sandstone and siltstone which give rise to soils ranging from shallow and stony to deep and well developed. Surface textures are generally silt loam; and B horizons, when present, are usually silty clay loam or silty clay. Soils derived from schists and gneisses tend to be deep and unstable and at least moderately fine textured. Soils formed in peridotite and serpentine are invariably bright red and fine textured. Despite the presence of clay-textured B horizons, the soils are seldom deeper than 1 meter. Soils derived from granitic parent materials are generally of sandy texture and low fertility. In many areas, weathered material is deep and soil formation, generally podzolization, is well advanced. Metavolcanic and metasedimentary rocks give

rise to a wide variety of soils. Well-developed soils are generally brown with loamy surface horizons and clay loam subsoils.

The most widely distributed great soil group is the Reddish Brown Lateritic. These soils occupy low to moderate elevations throughout the province. Less common soils in drier locations include Sols Bruns Acides, Noncalcic Brown, and Western Brown Forest soils. On the higher peaks, Lithosol, Rockland, and Podzol soils predominate. At lower elevations, soils formed under grassland vegetation fall within the Grumusol and Prairie great soil groups. These soils are extensive in central Jackson County. Alluvial and Humic Gley soils occupy low-lying depressions and scattered areas along principal streams.

Willamette Valley Province

The Willamette Valley is a broad structural depression oriented north-south and situated in Oregon between the Coast Ranges on the west and the Cascade Range on the east. The valley is approximately 200 kilometers long, extending from the Columbia River to Cottage Grove where the two mountain ranges converge. Valley width generally ranges from 30 to 50 kilometers. Topographically, the valley is characterized by broad alluvial flats separated by groups of low hills (e.g., Portland, Chehalem, Eola, Salem, and Coburg Hills) (fig. 6). The valley floor has a very gentle, north-facing slope; elevation increases from 50 meters at Salem to only 129 meters at Eugene, 130 kilometers to the south. As a result, the Willamette River is a sluggish stream with many meanders, especially from Oregon City southward.

The Willamette Valley is bordered on the west by a variety of sedimentary and volcanic rocks of Eocene age. They include submarine pillow basalts, conglomerates, and tuffaceous sandstones and siltstones which are actually eastward extensions of Coast Ranges formations. In the southern portion of the valley, these Eocene rock formations probably extend under valley fill materials to the western margin of the Cascade Range. Marine sedimentary rocks of Oligocene and Miocene age outcrop along the eastern margin of the valley. Columbia River Basalt (Miocene) is found as far south as the Salem area and caps the Portland, Salem, and Eola Hills. Similar early

Figure 6. — The Willamette Valley in Oregon is characterized by broad, almost level alluvial terrain interrupted by low basalt hills.

Miocene basalt flows occur in the Eugene area where, for example, they are found in the Coburg Hills. A westward extension of the Cascade Andesites of Plio-Pleistocene age outcrops near Gresham and caps many of the hills near Oregon City.

The floor of the northern Willamette Valley is underlain by thick, nonmarine sedimentary deposits of Plio-Pleistocene age. These deposits are present but not as thick in the southern part of the valley. Following the Illinoian glaciation late in the Pleistocene epoch, the entire valley as far south as Eugene was drowned by water and partially filled with silt to a depth of about 30 meters. Later, near the close of Wisconsin glaciation (10,000 to 15,000 years ago), the valley was again flooded because of an ice dam on the Columbia River. Evidences of this flooding include ice-carried erratics as far south as Harrisburg and a thin covering of silt to a maximum elevation of 122 meters. Recent alluvial deposits occur along the Willamette River in areas where it has cut into Pleistocene lake beds.

Soils on the valley floor, derived from silty alluvial and lacustrine deposits, were formed under dominantly grassland vegetation. Soil morphology largely reflects effects of soil drainage, which ranges from well to very poorly drained. Well-drained soils are moderately dark in color and, typically, silt loams. Most of the more poorly drained soils are darker colored with higher clay contents. Terrace soils usually have horizons of clay accumulation, whereas flood-plain soils do not. Soils derived from igneous and sedimentary rocks situated along the edges of the valley and in low hills are similar to those found in the adjacent Coast Ranges and Western Cascades provinces.

Over most of the Willamette Valley province, Prairie soils are dominant, intermixed with lesser amounts of Planosol and Alluvial soils. Soils of more limited occurrence include Humic Gley, Gray-Brown Podzolic, Chernozem, Reddish Brown Lateritic, and Grumusol.

Puget Trough Province

The Puget Trough province extends the entire length of Washington from the Canadian border to Oregon where the Willamette Valley is its physiographic and geological continuation. The northern half of the province includes Puget Sound, and the southern half is largely the Cowlitz River Valley and upper basin of the Chehalis River. Relief is moderate, and elevations of the trough floor seldom exceed 160 meters.

The northern, or Puget Sound basin, portion of the province is a depressed, glaciated area which is now partially submerged. The geology and topography resulted almost entirely from a lobe of the cordilleran ice cap which pushed into the area from the north during the Pleistocene epoch. There were apparently several glacial epochs, the Vashon glaciation being most recent. The terminal moraine of the Vashon glacier is located approximately 16 to 24 kilometers south of Olympia. Inside the moraine is a large area, sloping gently toward Puget Sound and containing many lakes and poorly drained depressions underlain by glacial drift. Glacial deposits range from very porous gravels and sands to a hard till in which substantial clay and silt are mixed with coarser particles. For approximately 50 kilometers south of the terminal moraine (as far south as Toledo), the area is largely covered by outwash sands and gravels which were sluiced southward by the melting Vashon glacier.

Tertiary rock formations are exposed in the southern portion of the province (south of Toledo). Topographic characteristics, however, are similar to those further north. The majority of the area is made up of Eocene basalt flows and flow breccia. Smaller areas of Miocene and Pliocene nonmarine sedimentary rocks are found south of Toledo and east of LaCenter. Immediately north of the Columbia River is a substantial area of Pleistocene lacustrine deposits, similar to those found in the Willamette Valley.

The majority of soils in the Puget Sound basin portion of the province are formed in glacial materials under the influence of coniferous forest vegetation. Brown Podzolic soils are most common. They generally have at least a moderately thick forest floor with some development of an H layer. A thin, weakly developed A2 horizon is typical beneath the humus layer. The iron- and humus-enriched B horizon is usually reddish-

brown, with textures reflecting the parent material. Associated soils include Gray Wooded, Regosols, and Lithosols. At several locations, notably east of Olympia, soils formed under grassland vegetation are common. In well-drained situations, Prairie soils predominate, with Alluvial and Humic Gley soils in streamside or depressional locations.

In the southern portion of the province, Reddish Brown Lateritic soils are the most widely distributed. They have reddish-brown, well-aggregated loam to clay loam surface horizons underlain by B horizons generally showing evidence of clay accumulation. Associated upland soils are Sols Bruns Acides and Lithosols. Alluvial and Humic Gley soils are common in low-lying areas.

Northern Cascades Province

The Northern Cascades province extends north from Snoqualmie Pass to the Canadian border. Unlike the Southern Cascades, these mountains are to a large extent comprised of ancient sedimentary rocks, most of which are folded and at least partially metamorphosed. Intrusions of large granitic batholiths are also common.

The province is a topographically mature area of great relief. Valleys are uniformly very deep and steep sided (fig. 7). An outstanding feature of the main eastward- and westward-flowing streams is their low gradient to within 6 or 7 kilometers of the main divide. On this basis, it may be concluded that the Northern Cascades are as deeply dissected as is possible with their present elevation and that their relief within the current erosion cycle is at a maximum. Another striking topographic feature is the approximately uniform elevation of the main ridgetops. Near the middle of the range, this level varies from 1,800 to 2,600 meters. Towering above this relatively even crest are two dormant volcanoes — Mount Baker and Glacier Peak. In addition to the volcanoes, there are several granitic peaks of exceptional height.

Figure 7. — The Northern Cascades province of Washington is characterized by unusually deep dissection and maximum relief; the steep-sided, U-shaped, main valleys are the result of glaciation.

Many ridges and peaks have glacial features. There are literally hundreds of cirques; some peaks, ringed by cirques, have been eroded to matterhorns. In addition, main east-west valleys probably owe their very low gradients to glaciation.Today this portion of the Cascades contains more active glaciers than any other area within the continental United States (fig. 8).

The geologic history of the area began late in the Paleozoic era with deposition of clastic marine sediments in a constantly falling geosyncline. These were metamorphosed during a period of compression and folding when the sea withdrew during the Jurassic period. Products of this metamorphism include argillite, slate, phyllite, schist, greenschist, and greenstone — rock types widely distributed throughout the Northern Cascades province. Gneisses, which occupy a large portion of the central section of the province, are also products of this same period of metamorphism. During early Cretaceous times, another geosynclinal trough was formed and the area reinvaded by the sea. Resulting rocks include mainly graywacke, siltstone, slate, phyllite, and argillite. These rocks, perhaps not as widespread as the older deposits, are located (1) north of Mount Baker, (2) between the Skykomish and Stillaguamish Rivers, (3) north of the town of North Bend, and (4) in the northeastern portion of the province (fig. 9). Sometime during the late Cretaceous period the sea withdrew. Sediment deposition continued on the west, however, where there was

Figure 8. — Extensive glaciers and snowfields are significant alpine features in the Northern Cascades province; view of Mount Shuksan (2,781 m.) with Mount Baker (3,285 m.) in the background.

a broad plain with meandering rivers. Here, continental sedimentary formations were laid down during late Cretaceous and early Paleocene times.

The Cascade Range was gradually uplifted during the Pliocene epoch. However, prior to this time large quantities of granitic rocks intruded the preexisting strata. Large masses of these rocks, including granite, granodiorite, and quartz diorite of Tertiary age, outcrop near the crest of the range in both the southern and northern portions of the province. In addition, older, Mesozoic granite rocks occupy large areas to the east.

The volcanic peaks of Mount Baker and Glacier Peak were built up during the Pleistocene epoch, chiefly of andesite flows. At the same time, glacial till was deposited in virtually every major valley. These deposits are highly variable and may range from fine to coarse texture. Generally, the fine material is glaciolacustrine in origin.

Extreme variability of parent materials combines with effects of extensive glaciation to produce a soil pattern in the Northern Cascades province bewildering in complexity. Residual rock is either frequently covered by or intimately mixed with glacial materials.

Figure 9. — An area of Cretaceous sedimentary rock (Swauk sandstone) northwest of Wenatchee, Washington; the steeply tilted beds of sandstone are clearly visible in this area of highly erodible soils.

Soils developed from glacial materials differ considerably, depending on whether they are derived from indurated till, loose outwash, and morainal materials or from fine-textured lacustrine deposits. Another important factor is the rapid pace of geologic erosion on steep slopes, which in many areas restricts soil formation to the extent that Lithosols and Rocklands are common.

Very little specific soils information is available for the province. However, a soil survey of a limited area (Gilkeson et al. 1961) identified several Podzol soil series derived from basalt and andesite colluvium and glacial drift. These soils have a 3- to 8-centimeter-thick, grayish, A2 horizon of sandy loam or loamy sand texture. The underlying soil is brown to reddish brown as a result of iron staining and is generally gravelly silt loam in texture. With the exception of soils formed on indurated glacial till which were classed as imperfectly drained Podzols, all soils in the area were well drained.

The most widely distributed great soil groups in the Northern Cascades province are Podzol, Brown Podzolic, and Lithosol. Other, less abundant soils include Rocklands and Regosols. In subalpine areas, the most common soils are Alpine Turf, Rockland, and Alpine Meadow. In the drier, southeastern portion of the province, Western Brown Forest, Gray Wooded, Chestnut, and Lithosol soils replace the podzolic soils found in higher rainfall areas.

Southern Washington Cascades Province

The Southern Washington Cascades province extends south from Snoqualmie Pass to the Columbia River. Unlike the Northern Cascades, andesite and basalt flows dominate with only minor amounts of igneous intrusive, sedimentary, and metamorphic rocks.

The area is characterized by generally accordant ridge crests separated by steep, deeply dissected valleys. The general ridge elevation is approximately 2,000 meters in the northern section and 1,200 meters in the southern. An extensive area around Mount Adams is composed mainly of recent lava flows; it comprises a gently sloping plateau at 900- to 1,500-meter elevation, differing markedly from the rest of the province. Three dormant volcanoes dominate the surrounding landscape: Mount Rainier (4,392 m.), Mount Adams (3,801 m.), and Mount St. Helens (2,948 m.) (fig. 10).

At least 90 percent of the Southern Washington Cascades province is made up of andesite and basalt flows with their associated breccias and tuffs. These lava extrusions have been classified into four rather generalized age classes: (1) Eocene to lower Oligocene, (2) upper Oligocene to lower Miocene, (3) middle Miocene, and (4) Pleistocene to Recent. The Eocene-Oligocene volcanic rocks are described as bedded andesitic breccias with interbedded andesite and basalt which have been considerably altered by faulting and folding. These rocks are widely distributed from Mount Rainier southward, largely west of the Cascade Range crest. The Oligocene-Miocene volcanic rocks are mainly andesite flows and flow breccias which, to a large extent, retain a fresh look and are in a horizontal position. These rocks outcrop in a large area north of Mount Rainier and at scattered locations to the south. The Miocene deposits are Columbia River Basalt which extends into the province from the east. Pleistocene to Recent deposits include the andesite flows and pyroclastics

which comprise the slopes of Mount Rainier, Mount Adams, and Mount St. Helens. Pleistocene to Recent vesicular basalt lavas are especially widespread in the vicinity of Mount Adams.

Tertiary granitic rocks are found only at scattered locations. The largest outcroppings are north and east of Mount Rainier. Another area of granodiorite is southwest of Randle. Small deposits of sedimentary rocks are located southwest of Mount Rainier and in the northeastern corner of the province. These include Eocene and Miocene sandstone, siltstone, and shale.

Areas adjacent to the three volcanic peaks are generally mantled with pumice deposits of variable age, origin, and thickness. Deposits near Mount St. Helens sometimes exceed 200 or 300 centimeters. The most recent pumice deposit in the vicinity of Mount Rainier is thought to have been laid down 100 to 150 years ago during the volcano's last eruption.

Pleistocene glacial activity was widespread in the Southern Cascades, although most were small alpine glaciers. At its maximum extension, the Puget Glacier pushed into the flanks of the Cascades, impounding long lakes in several mountain valleys. Today deep glaciolacus-

Figure 10. — Mount St. Helens in the southern Washington Cascades province; the Kalama River valley in the foreground contains an extensive mudflow deposit which can be traced in this photograph to its origin on the slopes of the mountain.

trine deposits mark the limits of these lakes.

Fewer soils in the Southern Washington Cascades province are developed in glacial materials and, because of generally less rugged topography, there are smaller areas of Rocklands and Lithosols than in the Northern Cascades. Soils developed in andesite and basalt range widely in profile characteristics varying from stony Lithosols to deep, well-developed Reddish Brown Lateritic soils. Soils with at least moderate development commonly have brown to reddish-brown loam or silt loam surface horizons underlain by B horizons of clay loam or silty clay loam texture. In many locations, the surface soil is mixed with or entirely composed of pumice particles. Glacial or glaciofluvial materials often give rise to moderately well drained to imperfectly drained Brown Podzolic or Gray-Brown Podzolic soils. These soils are characteristically sandy loam in texture, and B horizons are iron stained and often contain iron concretions. Soils in areas of deep pumice deposits are most often Podzols or Brown Podzolics. Podzolic soils on pumice typically have gray sandy A2 horizons over a reddish gravelly coarse sand B2ir horizon.

The most common soils are Podzols in the northern and Brown Podzolic soils in the southern portion of the province. These are accompained by substantial areas of Rockland, Lithosolic, and Regosolic soils, especial-

Figure 11. — The western Cascades of Oregon are deeply dissected with the higher ridges generally composed of thick flows of andesite; this view shows Twin Buttes in the foreground and the Three Sisters, located in the High Cascades province, in the background.

ly on steep terrain. Along the western boundary of the province, Reddish Brown Lateritic and Lithosolic soils are most abundant. Other less important soils in the west include Sols Bruns Acides, Regosol, Alluvial, and Humic Gley. On the eastern slopes of the Southern Washington Cascades province, the major groups include Western Brown Forest, Lithosol, and Chestnut soils.

Western Cascades Province

The Cascade Range in Oregon is divisible into two distinct physiographic provinces. The High Cascades province, on the east, includes all major peaks of the range (e.g., Mount Hood, Mount Jefferson, Three Sisters) and originated during late Pliocene and Pleistocene epochs. The Western Cascades province consists of older volcanic flows and pyroclastics laid down during the Oligocene and Miocene.

The relief of the Western Cascades province is generally rugged in the eastern portions (fig. 11), but slopes are more gentle in the west. Over much of the area there is a striking accordance of main ridge crests at an average elevation of about 1,500 meters. Elevations higher than 1,500 meters are uncommon, and only a few peaks exceed 1,800 meters.

During the Oligocene and Miocene epochs, numerous volcanic eruptions and effusions produced deposits of basalts, andesites, and pyroclastic rocks, frequently in a complex pattern. Pyroclastic rocks in this area include tuffs, breccias, and agglomerates. Besides these extrusive igneous rocks, a small amount of granite outcrops in several places, notably along the McKenzie River. Subsequent alteration by alpine glaciation occurred during the Pleistocene epoch. Glaciation is evidenced by widely spaced deposits of glacial drift and the characteristic U-shape of the major valley drainages.

Pyroclastics are abundant in the central portion of the Western Cascades province. Between the McKenzie and South Umpqua Rivers, approximately three-fourths of the total area is made up of pyroclastic rocks. To the north, breccias are almost entirely absent except in the Collowash and certain sections of the Santiam River drainages. South of the Umpqua basin, pyroclastics remain common to the Rogue River which marks their southernmost boundary.

Basalt and andesite are the most common bedrock materials in the Western Cascades province. A large proportion of the province is made up of andesite from the North Fork of the Willamette River northward to the Clackamas River. Also, south of the South Umpqua River, andesite is again the most common rock. Basalt has a more scattered occurence and is generally found along the western margin of the Western Cascade province.

Glacial deposits are widely distributed throughout the Western Cascades province, with the majority concentrated in the valleys of major streams. Tracing the exact extent of mountain glaciation in this area is very difficult because many morainal features have been obliterated by subsequent stream dissection.

Most of the soils of the Western Cascades province can be placed into two major groups — soils developed from pyroclastic parent materials (largely tuffs and breccias) and those derived from basic igneous rocks (mainly basalt and andesite). These parent material groupings produce strongly contrasting soil types. Since tuffs and breccias are readily weatherable, soils from these materials tend to be deep and fine textured, especially on gentler slopes. Pyroclastic soils are frequently imperfectly drained, and mass soil movements (e.g., slumps and earth flows) are common. Well-developed soils from tuffs and breccias typically possess moderately thick, dark-brown clay loam A horizons and olive-brown to reddish-brown silty clay or silty clay loam B horizons. On steep slopes regosolic gravelly clay loam soils are most common.

Soils derived from basalt and andesite are generally well drained and stonier and coarser textured than those from pyroclastic parent materials. These soils are more stable and not as subject to mass erosion. Most often, soils from basalt and andesite are relatively poorly developed, consisting of dark-brown gravelly loam or sandy loam surface horizons. Especially at higher elevations, surface layers often contain noticeable amounts of aerially deposited volcanic ash and pumice.

Most middle to high elevational soils in the central and eastern portions of the province are classed as Brown Podzolic or Regosols. Other less important soils in this zone include Podzol, Rockland, Lithosol, and Reddish Brown Lateritic soils. At lower elevations along the western margin of the province, Reddish Brown Lateritic soils are most abundant. Other groups represented here include Sols Bruns Acides, Noncalcic Brown, Prairie, Alluvial, and Humic Gley soils.

High Cascades Province

The High Cascades province is essentially an area of rolling terrain interrupted at intervals by glaciated channels, some quite deep, carrying westward-flowing streams. The area is dotted with volcanic peaks and cones rising to 50 to 1,600 meters above the surrounding area (fig. 12). The major peaks are, from north to south, Mount Hood (3,427 m.), Mount Jefferson (3,199 m.), and the Three

Figure 12. — The High Cascades province of Oregon is essentially a gently sloping, high plateau area containing scattered volcanic peaks composed of andesite and smaller "cinder cones"; peaks on the skyline are Mount Jefferson (3,250 m.) on the left and Three-Fingered Jack (2,389 m.) on the right and the cratered cinder cones in the foreground comprise Sand Mountain.

Sisters (3,062-3,157 m.). The general elevation of the sometimes broad, gently sloping portion is approximately 1,500 to 1,800 meters.

The High Cascades province is geologically young; some flows of lava (scoriaceous basalt) are only several hundred years old. The most extensive depositions were extruded from volcanic vents during the late Pliocene and Pleistocene epochs. These flows are of gray olivine basalts and olivine-bearing andesites with subordinate amounts of dense porphyritic pyroxene andesites. Scattered over the area are younger flows comprised of andesites and basalts which are dated as upper Pleistocene and Recent epochs. Most major peaks in the area are made up of olivine-bearing andesite and originated during the upper Pleistocene epoch. The smaller cones, commonly called cinder cones, are generally comprised of gray to red basaltic and andesitic pyroclastic rocks.

Bedrock in the High Cascades province is frequently obscured by a mantle of pumice and ash from several volcanic eruptions. The most extensive deposition of these materials resulted from the explosive culminating eruption of Mount Mazama, which occurred about 6,600 years ago.

Glacial deposits are also locally abundant, especially adjacent to some of the higher peaks. For example, the flanks of Mount Hood are typically mantled with deep deposits of glacial till.

Very little specific soils information is available for the High Cascades province except for a limited area west of Mount Hood. There, parent materials are largely glacial till producing Podzol and Brown Podzolic soils. Surface horizons range from black to gray with textures of sandy loam or silt loam. Subsoils are dark-brown to dark reddish-brown gravelly or stony clay loam. Till deposits are deep, and the soils are well drained.

In the central portion of the province, extensive areas are mantled with deposits of volcanic ejecta such as pumice, cinder, and ash. Soils in these materials generally exhibit little profile development and are classed as Regosols. Typically, a thin A1 horizon of sandy loam or loamy sand texture is underlain by a transitional AC horizon which grades into the unaltered coarse sand or gravelly sand parent material.

Throughout most of the province, Regosol and Brown Podzolic soils are most abundant. Other soils of more limited occurrence include Podzol, Rockland, and Lithosol. In the Columbia Gorge area to the north and in the southern extremity of the province, Western Brown Forest, Regosol, and Lithosol soils predominate.

Okanogan Highlands Province

The Okanogan Highlands province is characterized by moderate slopes and broad, rounded summits. In this respect, it differs markedly from the rugged North Cascades province on the west. Excepting the main river valleys, much of the province lies above 1,200 meters. There is a scattering of peaks which attain elevations of over 2,400 meters. The province is made up of several upland areas separated by a series of broad, north-south river valleys. These south-flowing rivers are, from west to east, the Okanogan, Sanpoil, Columbia, Colville, and Pend Oreille (Clark Fork) Rivers.

Virtually the entire province was repeatedly covered by glacial ice during the Pleistocene epoch. As a result, deposits of glacial drift are found throughout the area. Although many of these deposits occur only intermittently in stream valleys, they are widespread in the eastern portion of the province, especially north of Spokane. In some of the main valleys, glaciolacustrine sediments form a series of terraces on valley walls.

The Okanogan Highlands province is, in many respects, geologically similar to the North Cascades province. There is an almost bewildering variety of rock types present, ranging in age from Precambrian to late Tertiary. The Precambrian rocks, consisting largely of phyllite, are restricted to the eastern portion of the province. Lying above these deposits are rocks of the Cambrian, Ordovician, Devonian, and Mississippian periods of the Paleozoic era. Rock types represented in these formations include quartzite, graywacke, slate, argillite, phyllite, greenstone, and some limestone. The most abundant rock types in

the province are granitics, which were deposited during the Mesozoic era. These rocks, which include granite, quartz monzonite, quartz diorite, and granodiorite, occupy most of the area in the western section of the province and are interspersed with the Paleozoic rocks to the east. Tertiary depositions are largely confined to areas adjacent to main river valleys. Bedded Tertiary sediments are found near the Okanogan, Sanpoil, Columbia, and Pend Oreille Rivers. Later in the Tertiary period these same areas were influenced by eruptions of andesite and basalt lavas. Columbia River Basalt (Miocene) extends across the Columbia River into the province in an area south of Okanogan.

In the Okanogan Highlands province, the soil pattern is closely tied to elevation. In the mountainous areas away from the major river valleys, soils tend to be cold, acid, stony, and are often shallow to bedrock. In many areas, soil profiles are poorly developed and exhibit little horizonation. In other locations, especially at higher elevations, soils often show some effects of podzolization and possess a thin or intermittent A2 horizon underlain by a B2 horizon of high iron content.

At lower elevations along river valleys and the southern boundary of the province, soils reflect the drier climate and transitional forest-grassland vegetation. These soils typically have a dark, moderately thick, A1 horizon underlain by a B horizon which shows little increase in clay content and is distinguished largely by changes in color and structure. Soil textures are commonly sandy loam to loam.

Mountain soils are generally classed as Brown Podzolic, Gray Wooded, or Lithosols. Other less extensive soils include Humic Gley, Regosol, and Rockland. Soils in the forest-grassland transition at lower elevations are Western Brown Forest, Gray Wooded, and Lithosols. Soils formed under grass or grass-shrub communities are scattered throughout the province. These include Chernozem, Brown, Lithosol, and Alluvial soils.

Figure 13. — The Wallowa Mountains of Oregon are more deeply dissected and have steeper slopes than other sections of the Blue Mountains province; snowcapped peaks in the background include Eagle Cap, the highest in the range.

Blue Mountains Province

The Blue Mountains province is made up of several ranges of mountains separated by faulted valleys and synclinal basins. The mountainous areas include the Ochoco, Blue, and Wallowa Mountains, as well as the Strawberry, Greenhorn, and Elkhorn Ranges. Relief within the various mountain ranges is highly variable. Moderate slopes are common within the Blue and Ochoco Mountains, whereas the heavily glaciated Wallowa Mountains exhibit the greatest relief (fig. 13). Maximum elevations range from about 2,100 meters in the Ochoco Mountains to 2,900 meters at Eagle Cap in the Wallowa Mountains. Valley elevations are about 750 meters in the vicinity of the Ochocos and 900 meters in the broad basin between the Blue and Wallowa Mountains (near LaGrande and Baker, Oregon). Spectacular Hells Canyon comprises the eastern boundary of the province. This canyon, occupied by the Snake River, ranges up to 1,660 meters in depth and is 24 kilometers wide at its broadest point.

Geologically, the Blue Mountains province may be conveniently separated into eastern and western units, with the dividing line a short distance east of John Day, Oregon. The western Blue Mountains contain outcrops of some of the oldest rocks in Oregon. These are Paleozoic formations (Mississippian and Penn-

sylvanian) of limestone, mudstone, and sandstone which outcrop along tributaries of the upper Crooked River. Ultramafic intrusions, some altered to serpentine, occur in the Strawberry Range. Triassic and Jurassic formations are located near the communities of Suplee and Izee and consist of a wide range of rocks such as conglomerate, sandstone, siltstone, shale, and limestone. The Clarno (Eocene) and John Day (Oligocene) are two formations widely known because of their abundant vertebrate fossils. Located along the lower John Day River, these formations are composed largely of breccia and varicolored tuffs. Columbia River Basalt, a thick formation extruded in many sheets during the Miocene epoch, occupies large areas within the western Blue Mountains. Late Miocene and Pliocene formations are also present and consist of bedded tuffs and silts.

The eastern portion of the Blue Mountain province spans a large part of the geologic time scale. Paleozoic formations of the Permian period are widespread near Baker and Sumpter and consist of schists, limestone, slate, argillite, tuff, and chert. As in the western section, these formations often have ultramafic and mafic intrusions ranging from peridotite to gabbro. Triassic sedimentary formations (sandstone, siltstone, shale, and limestone) are common but are not continuous because of erosion and subsequent burial by Tertiary rocks. Triassic limestone and argillaceous beds are especially prominent in the Wallowa Mountains where they outcrop on many ridge crests. Granitic stocks, perhaps extensions of the great Idaho Batholith, are found in the Wallowa Mountains, near Baker and Sumpter and along the John Day River. Columbia River Basalt is widespread along the north slope of the Blue Mountains, forms the mass of the range between Pendleton and La-Grande, and is also found to the south. Thus it is inferred that uplift of the Blue Mountains occurred after the deposition of these lavas during the Miocene epoch. Alluvial deposits of sand and gravel, dating from the Pliocene and Pleistocene, cover the floors of many basins. Also during the Pleistocene, glaciation was widespread in both the Blue and Wallowa Mountains, as shown by numerous cirques, glacial lakes, and moraines.

Following deposition of the most recent lava flows, much of the area within the central and northern portions of the Blue Mountains was covered by a layer of aerially deposited volcanic ash and fine pumice. Subsequent erosion has largely removed the ash from south-facing slopes; however, other locations are typically mantled by the material.

At the present time, considerably more soils information is available for the western portion of the province (Ochoco and Blue Mountains) than for the Wallowa Mountains. Soils in the western section include those derived from basic igneous flow rocks, acid igneous rocks and pyroclastics, and volcanic ash. Many of the soils developed on basalt and andesite tend to be shallow and lithosolic and at least moderately fine textured. Surface horizons are generally comprised of dark-brown loam or silt loam, and subsoil textures range from clay loam to clay. Soils derived from rhyolite and tuff also are commonly shallow and lithosolic; however, they are considerably more coarse textured. Most often, the soil material is a dark-brown sandy loam of very weak structure. Soils derived from volcanic ash may occur over either bedrock or buried soil material. Thickness of the ash mantle varies, but most often it is in the range of 1/2 to 1 meter. Volcanic ash gives rise to soils characteristically dark brown in color and fine sandy loam in texture.

Most of the soils in the mountainous, central portion of the province which have formed under forest vegetation are classed as Western Brown Forest, Regosol, or Lithosol soils. Other forest soils of more limited extent include Brown Podzolics and Reddish Brown Lateritics. In the eastern portion of the province, there are several upland areas possessing soils formed under grassland or shrub-grassland vegetation. Principal great soil groups represented in these areas include Chernozem, Chestnut, Prairie, and Lithosol. At lowest elevations, especially along the boundaries of the province, Chestnut and Lithosol soils predominate. Alpine Turf, Rockland, and Alpine Meadow soils are found on some of the higher peaks within the Wallowa Mountains. At the other extreme, Alluvial and Humic Gley soils are common in low-lying depressions and along major streams.

Figure 14. — Canyons cut in basalt by the Deschutes and Crooked Rivers in the southern portion of the Columbia Basin province; west of Madras, Oregon.

Columbia Basin Province

The Columbia Basin is the largest single province; it occupies an extensive area south of the Columbia River between the Cascade Range and Blue Mountains in Oregon and roughly two-thirds of the area east of the Cascades in Washington. Topography varies from very gently undulating to moderately hilly. Steep slopes are of limited occurrence and restricted to isolated basaltic buttes or canyons cut by some of the major rivers; for example, the Deschutes River in Oregon (fig. 14). Over most of the area, elevations range from 300 to 600 meters, although they are less than 150 meters adjacent to the Columbia River.

Although early Tertiary rocks are found at scattered locations in Oregon, the important geologic events in the Columbia Basin province began during the Miocene epoch with the vast outpouring of lavas making up the Columbia River Basalt formation. This huge basalt layer covers over 500,000 square kilometers in Washington, Oregon, and Idaho and underlies virtually the entire province. The Columbia River Basalt formation, ranging in total thickness from 600 to over 1,500 meters, is made up of numerous individual flows about 8 to

30 meters thick. Bottom portions of individual flows are dense, dark-gray basalt, but near upper margins the basalt becomes scoriaceous. In some areas, deformation of the Columbia River Basalt produced ridges and hills during the Pleistocene epoch.

In the central portion of eastern Washington's Columbia Basin province is a unique geologic feature — the Channeled Scablands. This is a gigantic series of dry, deeply cut channels in Columbia River Basalt (fig. 15) which form an extensive and complex drainage network. Many of the deeply entrenched drainageways diverge upstream only to converge again further downstream. Perhaps the best known feature in the Channeled Scablands is Grand Coulee with its spectacular Dry Falls. Although the origin of these puzzling features is still debated, Bretz (1959) probably offered the most satisfactory theory. He suggests that flood waters, pouring from glacial Lake Missoula (western Montana) as a result of dam failure during the Pleistocene epoch, were responsible for cutting the channels.

Plio-Pleistocene deposits cover the Columbia River Basalt over extensive areas. The most widespread deposit is the Palouse loess which mantles an elliptical area 160 kilometers long in southeastern Washington. This material, deposited during the Pleistocene epoch, is made up of massive, tan-colored silt which may be over 45 meters thick. The Palouse area is characterized by smoothly rolling hills (fig. 16) and soils of high fertility which are generally used for wheat and pea

Figure 15. — General view of channeled scabland in the Columbia Basin of central Washington; this area is characterized by numerous dry channels cut in Columbia River basalt and generally shallow, stony soils (*photo courtesy of H. W. Smith*).

Figure 16. — Rolling Palouse Hills, composed of deep loess deposits, near Pullman, Washington, Columbia Basin province (*photo courtesy of H. W. Smith*).

production. Similar buff-colored, structureless silt deposits are found in Oregon near Moro and in Grass Valley. In addition, a large area near Boardman, Oregon, is underlain by unconsolidated sand of apparently Pleistocene age. Similar deposits, probably glaciolacustrine in origin, are located west of Walla Walla and near Toppenish, Washington.

Although virtually all soils in the Columbia Basin province have been formed under grassland or shrub-grassland vegetation, a wide variety of soils is present. Most of the broad soil differences correlate with annual precipitation. In general, precipitation is heaviest along the margins of the basin and gradually decreases toward the central portion. As a result, four distinct soil regions, forming a roughly concentric circular pattern, may be identified within the province.

The first soil region is located along all province boundaries with the exception of the west but is best expressed in the Palouse Hills near the Washington-Idaho border. The climate is subhumid, with annual precipitation ranging from 400 to 600 millimeters. In this area, Prairie and Chernozem soils predominate. A typical Prairie soil derived from Palouse loess possesses a thick, dark-colored A1 horizon of silt loam texture overlying a clay loam or silty clay loam B2 horizon having well-defined prismatic structure. Typically, calcium carbonate has been leached to levels well below the base of the solum. Chernozem soils developed from similar materials generally have shallower profiles, less clay accumulation, and weaker prismatic structure in the B horizon and a zone of calcium carbonate in the B3, usually within 1 meter of the soil surface. Other soils encountered in this region include Chestnut, Alluvial, Lithosol, Regosol, and Planosol great soil groups.

The second region is adjacent but generally at lower elevations and more arid, receiving 230 to 400 millimeters of annual precipitation. The principal soils are Chestnut derived from loess. Typical Chestnut soils have moderately thick, brown silt loam A1 horizons over light-brown silt loam B horizons with incipient prismatic structure. A zone of calcium carbonate accumulation is present in the B3 horizon. Other soils present in smaller amounts include Chernozem, Brown, Lithosol, Alluvial, and Rockland.

The third soil region roughly encircles the central portion of the basin and also is semiarid with 230 to 400 millimeters of annual precipitation. Parent materials are principally loess and sandier windblown materials. Brown soils comprise the major zonal great group. They possess a moderately thick, dark grayish-brown, loam-textured A horizon which is low in organic matter content. B horizons show little clay accumulation and a B3ca is generally present. Lithosols are also common in this region since it encompasses a large portion of the channeled scablands. Other soils of some importance include Chestnut, Sierozem, Alluvial, Regosol, and Rockland.

The fourth soil region includes desertic soils of the lower bowllike center of the Columbia Basin province. This is an area of arid climatic conditions receiving 100 to 230 millimeters of precipitation annually. Here the dominant great soil group is the Sierozem. These soils have thin, light-colored A horizons over B horizons which may be darker than the A and usually contain larger amounts of clay. A carbonate-enriched horizon, that may be cemented, occurs in the lower part of the B horizon. Other soils present include Regosol, Lithosol, Alluvial, Solonchak, Brown, Rockland, Solonetz, and Humic Gley groups.

High Lava Plains Province

The High Lava Plains province of central Oregon is characterized by young lava flows of moderate relief interrupted by scattered cinder cones and lava buttes. As a result of porous bedrock and scanty rainfall, many streams are seasonal. Undrained basins containing playa lakes, some dry and others with fluctuating levels, are common. Several basins, now dry, contained extensive lakes during the Pleistocene epoch (e.g., Fort Rock valley and Christmas and Fossil Lakes). Most of the province has a base elevation of about 1,200 meters above sea level.

Geologic formations in the high lava plains consist largely of Pliocene and Pleistocene lavas, tuffs, and alluvium. In many areas,

Figure 17. — Lava Butte south of Bend, Oregon — an outstanding example of a Recent volcanic cone and associated lava flows located in the western portion of the High Lava Plains province.

Quaternary valley fill deposits overlie the older volcanic flows. These are comprised of alluvium and lake deposits plus eolian sediments, all of which were derived from the volcanic rocks of the uplands.

Evidences of extensive volcanic activity during Pleistocene and Recent times are abundant, especially in the western portion of the province. The largest volcanic peak is the Paulina Peak shield volcano which contains Newberry Crater. Pumice, resulting from an eruption of this volcano about 4,000 years ago, mantles an extensive area to the north and east of the crater. Deposits of Mount Mazama pumice are also widespread in the same general area, as well as to the south in the Basin and Range province. Broad areas of Pleistocene lava flows are a notable feature in the vicinity of Bend. In addition, several outstanding examples of Recent lava flows are situated south of Bend at Lava Butte (fig. 17) and east of Fort Rock.

Soils of the High Lava Plains province are similar to those occurring in the Basin and Range and Owyhee Upland provinces to the south and east. The central and eastern por-

Figure 18. — Hart Mountain, a typical fault-block mountain in the Basin and Range province of southeastern Oregon; note the internally drained depressions containing shallow, saline lakes.

tions, supporting shrub-grassland vegetation, are mantled mainly with Brown, Chestnut, and Lithosol soils. These soils are derived from alluvial and lacustrine sediments, as well as from residual basalt, andesite, and tuffs. Typical Chestnut soils within the province have moderately thick, very dark-brown loam A1 horizons and dark yellowish-brown clay or clay loam B2 horizons with some calcareous deposits on ped surfaces. Brown soils differ from the Chestnut in having shallower profiles, generally less clay accumulation in the B2 horizon, and a higher concentration of calcium carbonate in the lower section of the B. More restricted soils in this section of the province include Regosol, Alluvial, Solonetz, Solonchak, and Humic Gley.

In the western portion of the province, adjacent to the High Cascades province, regosolic soils developed on pumice support open coniferous forest vegetation. These are most extensive east of Newberry Crater where the younger Newberry pumice frequently overlies preexisting pumice deposits from Mount Mazama. These pumiceous Regosols are briefly described in the section covering the Basin and Range province.

Basin and Range and Owyhee Upland Provinces

Southeastern Oregon has been divided into two physiographic provinces: Basin and Range and Owyhee Upland. Although topography differs, the two provinces are similar geologically.

The Basin and Range province is characterized by fault-block mountains enclosing basins with internal drainage (fig. 18). The Owyhee Upland province exhibits considerably less faulting and in general may be described as a north-facing basin which is drained by the Owyhee River. Elevations in both provinces range from about 1,200 meters to 2,930 meters atop Steens Mountain. Except for slopes of the fault-block mountains, much of the area is rolling with low relief. Since annual precipitation in the area averages only 180 to 300 millimeters, most streams are intermittent and numerous undrained basins contain shallow, saline lakes.

Excepting small amounts of Paleozoic and Mesozoic formations which outcrop in the Pueblo and Trout Creek Mountains, virtually all rocks date from Miocene to Recent epochs. The western Basin and Range province is largely made up of Miocene to Recent flows of basalt, pyroclastics, and alluvial sediments. Further east two rock assemblages are prominent: (1) Miocene flows of rhyolite, dacite, and andesite near Abert Rim and Paisley; and (2) altered basalt and andesite flows and tuffs overlain by tuffaceous sedimentary rocks in an area just east of Lakeview. Principal fault-blocks in the area (Winter Ridge, Abert Rim, and Steens Mountain) are capped with Miocene flows of basalt. At the base of the Steens Mountain fault scarp are tuffaceous sedimentary rocks as well as flows of rhyolites, andesites, and dacites. Steens Mountain is also of interest because of evidences of extensive glaciation — glacial carved channels and cirque basins at the head of virtually every drainage (fig. 19).

To the east, near the Owhyee River, are Miocene and Pliocene beds of tuffaceous sedimentary rocks capped by flows of rhyolite and basalt. In addition, thick beds of quartzose sandstone, siltstone, and conglomerate

outcrop near the mouth of the Owyhee River. The most recent volcanic activity in the area occurred during the Pleistocene epoch and resulted in basalt flows of limited extent at Diamond (fig. 20) and Cow Lakes Craters.

Soils of these provinces may conveniently be divided into two main groups — those in the west which developed under forest vegetation and those in the east associated with grassland-shrub vegetation. A tree-covered high plateau area in the northwestern corner of the Basin and Range province is mantled with extensive deposits of Mount Mazama pumice. Although most was aerially deposited originally, the pumice has been reworked by water in some areas, or was deposited in glow-

Figure 19. — Kiger Gorge, a glacially carved valley penetrating Steens Mountain, eastern Basin and Range province, Oregon.

Figure 20. — Diamond Craters, source of Pleistocene basalt flows in the Owyhee Upland province of southeastern Oregon.

ing avalanches which swept down slopes near the volcano during the eruption. Soils derived from pumice have immature, regosolic profiles consisting of a moderately thick surface layer with some organic matter accumulation overlying nearly fresh, yellow- and buff-colored pumice gravel and sand. They are slightly acid and, due to the high porosity of the pumice particles, have water-holding and cation-exchange capacities far greater than generally expected in such coarse material.

South and east of the pumice plateau is open forest interspersed with shrub-grassland. Dominant soils in this area are Western Brown Forest, Regosols, and Lithosols. Soils of lesser importance include Chestnut, Chernozem, Prairie, and Reddish Brown Lateritics. Southeast of Klamath Lake, Humic Gley, Alluvial, and Chestnut soils are the most common.

In the eastern section of the Basin and Range province and in the Owyhee Upland province, Brown, Chestnut, and Lithosol soils are by far most abundant. A typical Brown soil profile developed from basalt possesses a dark-brown silty clay loam A1 horizon of medium thickness over a dark yellowish-brown clay B2 horizon having prismatic structure. A calcium carbonate cemented pan is generally present at a depth of approximately 60 centimeters.

Sierozem, Desert, and Alluvial soils are present in a drier area situated east of Steens Mountain. Other soils scattered throughout the southeastern section of Oregon include Solonetz, Solonchek, Regosol, Humic Gley, and Rockland.

CLIMATE

The varied climates of Oregon and Washington result from complex interplay between maritime and continental airmasses and the mountain ranges, particularly the Cascade Range that divides the States into eastern and western parts. Climatic data for representative stations in both areas are provided in table 2; this table, the isohyetal map (fig. 21), and the isoline maps for January mean minimum and July mean maximum temperatures (figs. 22 and 23) can be consulted during the following discussion.

Western Oregon and Washington have a maritime climate, characterized by:

1. mild temperatures with prolonged cloudy periods, muted extremes, and narrow diurnal fluctuations (6° to 10° C.);

2. wet, mild winters, cool, relatively dry summers, and a long, frost-free season; and

3. heavy precipitation (typically 1,700 to 3,000 millimeters or more on the coast and 800 to 1,200 millimeters in the Puget-Willamette trough), 75 to 85 percent of which occurs between October 1 and March 31, mostly as rain.

Most precipitation is cyclonic, the result of low-pressure systems that approach from the Pacific Ocean on the dominant westerlies. During summers, storm tracks are shifted to the north, and high-pressure systems bring fair, dry weather for extended periods.

There are some important variations in the climate of the western lowlands as a result of the coastal mountains and of latitude. Coastal mountains are responsible for the drier and less muted climate of the Willamette Valley, Puget Trough, and interior valleys of southwestern Oregon. The maritime airmasses are blocked from these areas to varying degrees, and precipitation declines markedly in resultant rain shadows (table 2). At the same time, there is a general latitudinal increase in precipitation from south to north. Consequently, the interior valleys of southwestern Oregon typically have hot, dry climates (see Medford in table 2).

Eastern Oregon and Washington combine features of both maritime and continental climates. Temperatures are milder than those in the Great Plains since the Rocky Mountains buffer the full brunt of the continental airmasses. Still, temperatures fluctuate more widely than west of the Cascades, diurnal fluctuations of 10° to 16° C. being typical. Winters are colder, summers are hotter, and frost-free seasons are shorter. Precipitation is still primarily cyclonic in origin, but is considerably less than to the west since the area lies in the rain shadow of the Cascade Range; annual precipitation is typically 250 to 500 millimeters. Precipitation is not quite as seasonal, only 55 to 75 percent of it occurring between October 1 and March 31, but summers (June through August) are very dry (30 to 70 millimeters). A high proportion of the annual precipitation falls as snow, which is relatively uncommon in the coastal areas.

Mountain masses have profound effects on the climatic regime. As mentioned, the Cascade Range is an extremely important barrier to the movement of maritime and continental airmasses. Within the Cascade Range, elevation has a primary effect on local climate. Precipitation and snowfall increase and temperatures decrease rapidly with elevation on both western and eastern slopes of the range (fig. 24). Similar phenomena occur more locally with smaller mountain masses. For example, precipitation is very high on the western slopes of the coastal ranges (Olympic Mountains, Coast Ranges, and Siskiyou Mountains) and rain shadows occur to the east. In eastern Oregon and Washington increases in precipitation and decreases in temperature are associated with mountain masses such as the Blue Mountains and Okanogan Highlands.

Some details of climate associated with individual vegetation types will be included in later sections. The reader should keep in mind (1) the basically mild, summer-dry regional climate, and (2) the blocking effects of mountain masses on westerly winds of maritime and northeasterly winds of continental airmasses.

Table 2. — Climatic data from some representative weather stations in Oregon and Washington

Area and Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
West of Cascade Range:											
Quinault, Wash.[1]	72	47°28′	123°51′	10.6	3.8	1.2	17.3	23.8	3,371	244	30
Otis, Oreg.[1]	49	45°02′	123°56′	10.3	5.3	2.00	15.3	20.1	2,496	163	--
Bellingham, Wash.[2]	34	48°47′	122°29′	9.5	2.7	−1.4	16.1	23.3	853	102	25
Seattle, Wash.[2]	34	47°39′	122°18′	11.6	4.5	1.1	18.7	24.1	888	79	29
Portland, Oreg.[2]	9	45°32′	122°40′	12.6	4.6	1.4	20.3	25.8	1,076	70	31
Medford, Oreg.[2]	400	42°22′	122°52′	11.4	1.9	−1.2	22.2	31.8	502	36	19
East of Cascade Range:											
Spokane, Wash.	718	47°37′	117°31′	8.8	−3.7	−7.8	23.9	28.7	437	58	147
Yakima, Wash.	323	46°34′	120°32′	9.9	−2.5	−8.9	21.7	31.3	200	29	64
Pendleton, Oreg.	455	45°41′	118°51′	11.6	.1	−4.3	23.1	31.2	314	42	47
Klamath Falls, Oreg.	1,249	45°12′	121°47′	9.1	−1.4	−6.4	20.4	29.6	357	40	104

[1] Coastal station.

[2] Station in lee of Coast Ranges.

Source: U. S. Weather Bureau (1965a, 1965b).

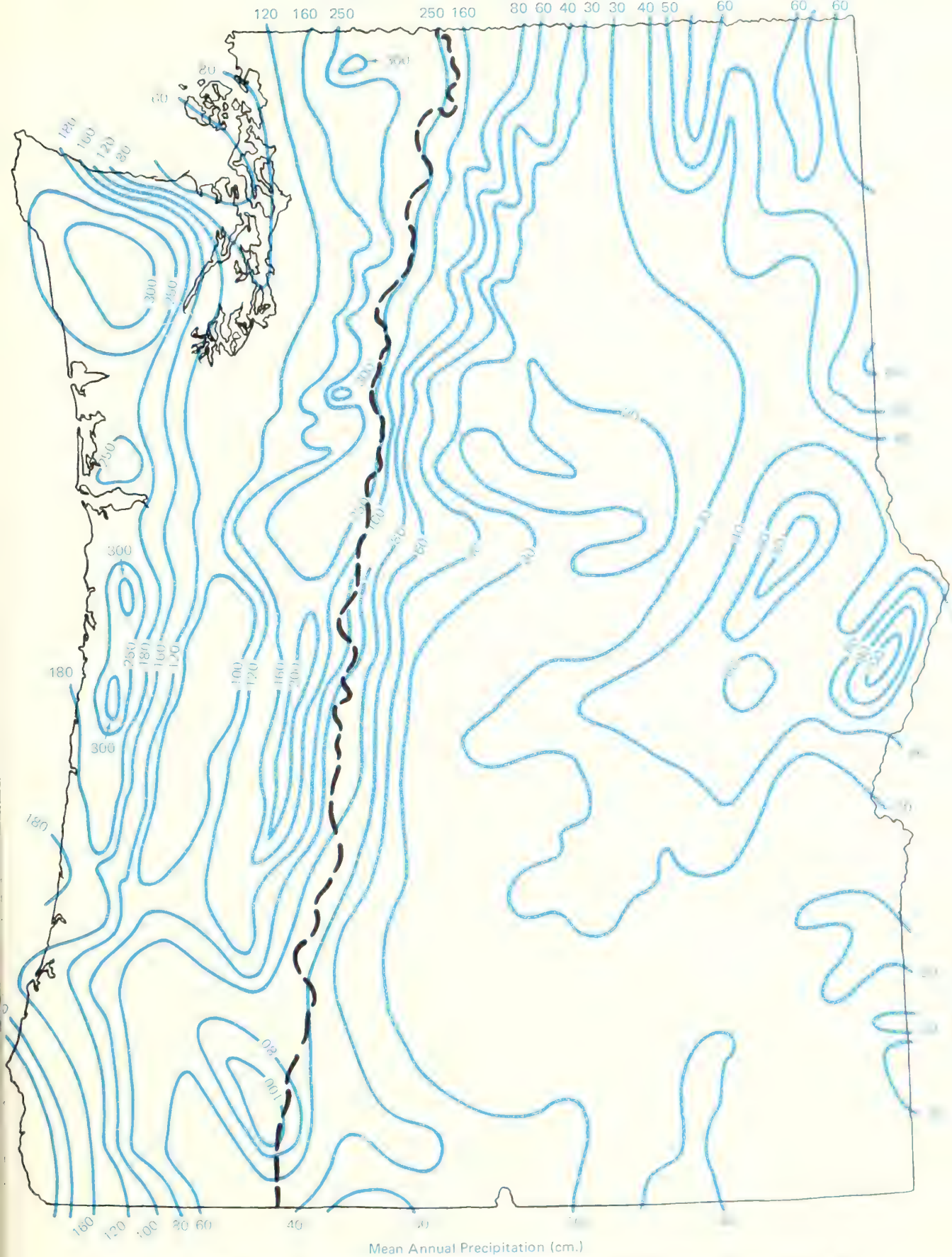


Figure 21. — Mean annual precipitation in Oregon and Washington (U.S. Weather Bureau 1960a, b).

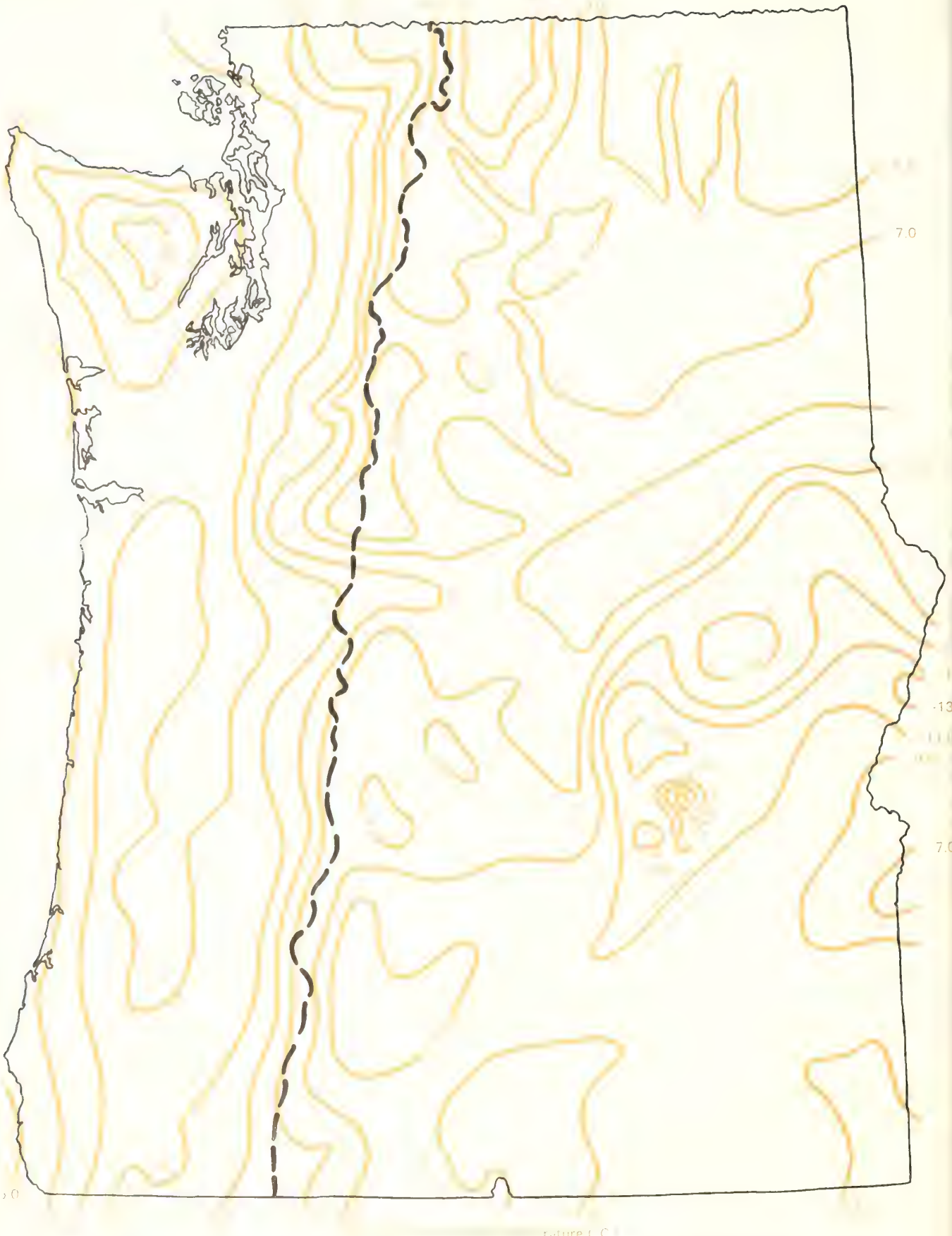


Figure 22. — January mean minimum temperatures in Oregon and Washington (U.S. Weather Bureau 1960a, b).

Figure 23. — July mean maximum temperatures in Oregon and Washington (U.S. Weather Bureau 1960a, b).

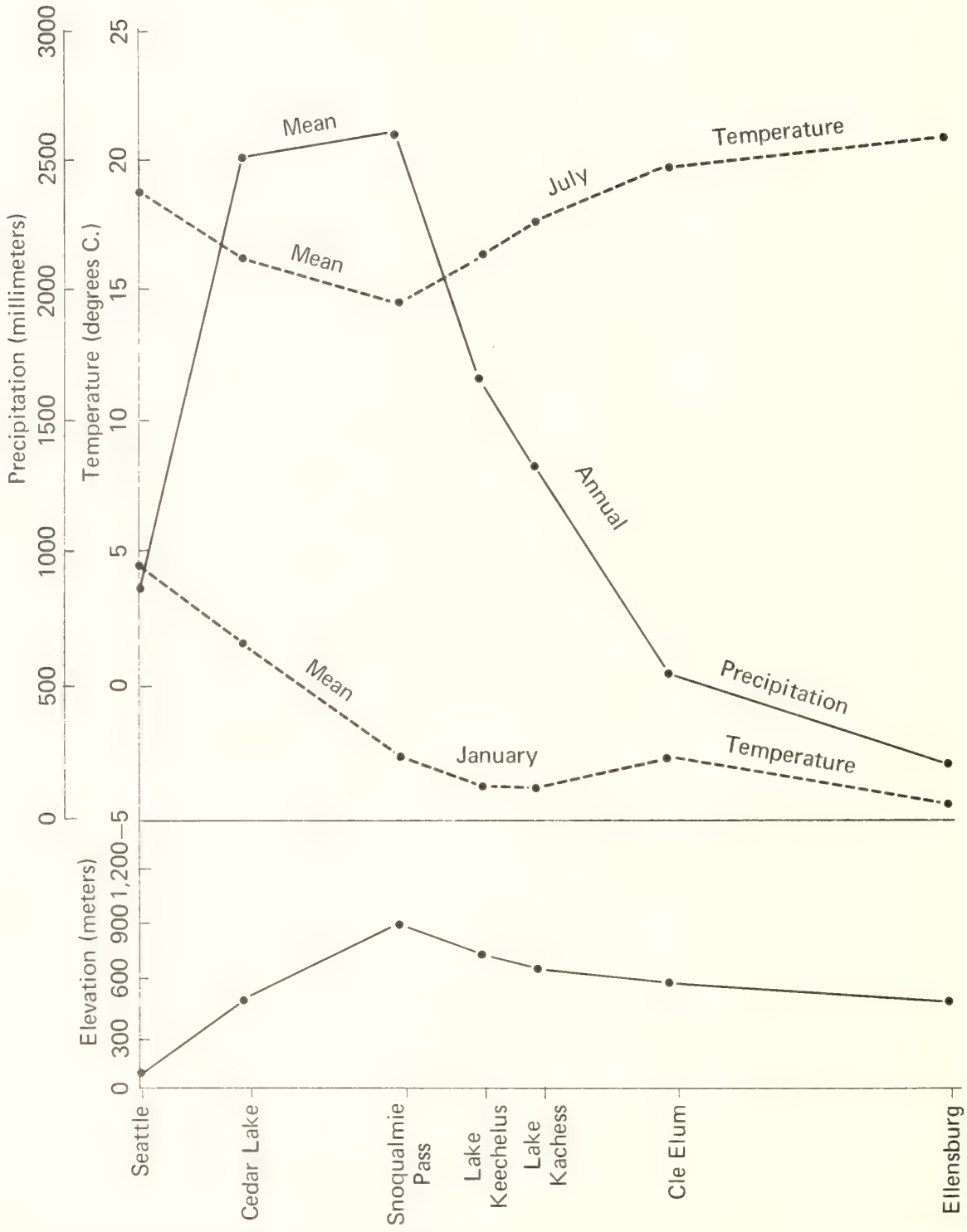


Figure 24. — Climatic cross section of the Cascade Range in the vicinity of Snoqualmie Pass, Washington (47°25′ N. lat.); distance from Seattle to Ellensburg approximately 152 km. (data from U.S. Weather Bureau 1956).

MAJOR VEGETATIONAL AREAS

Broadly classifying areas as (1) forest, (2) grass or shrub-grass (hereafter called steppe and shrub-steppe), and (3) subalpine parkland and alpine communities results in a major geographic separation (fig. 25). The forested communities are seen to be characteristic of western Washington and Oregon and mountainous areas to the east, and shrub-steppe or steppe lies almost entirely in the rain shadow east of the Cascade Range. The forests may be further subdivided into those found in (1) western Washington and coastal and northwestern Oregon, (2) interior southwestern Oregon and the Willamette Valley, and (3) eastern Oregon and Washington (east of the Cascade Range crest).

We have used zones as basic organizational units for the communities within the subdivisions just outlined. Zones of various types have been used for many years in biogeography, particularly in mountain regions. They have been defined by many criteria, such as climate, existing vegetation, and potential (climax) vegetation (Daubenmire 1946). Perhaps a zone is most usefully defined as the area in which one plant association is the climatic climax (Daubenmire 1968a). This delineates an area of essentially uniform macroclimate since the climax community on deep, loamy soils and undulating topography[3] is primarily a product of macroclimate. Such zones tend to occur sequentially along moisture and temperature gradients which extend through broad regions or up mountain slopes.

Vegetational zones based on climax vegetation are the organizational basis for much of this paper. Our scheme is imperfect, however, for many reasons. In some areas, data are insufficient for construction of such a system and a more typological approach must be used (e.g., in southwestern Oregon). In other cases, zonal or modal habitats (loamy soils and undulating topography) are rare or absent, such as in most of the mountainous areas and the major part of eastern Oregon. Consequently, our forested zones are based not on climatic climax communities but rather on areas in which a single tree species is the major climax dominant; e.g., *Pinus ponderosa* or *Tsuga heterophylla*.[4] These areas do tend to occur as zonal sequences. Typological systems are inadequate since they depend on existing vegetation and frequently emphasize widespread seral types that span widely varying environments or economically valuable species rather than biologic features.

Someday, northwestern communities might be organized along the lines of climax series as recently carried out by Daubenmire and Daubenmire (1968) in the forests of eastern Washington and northern Idaho, but available data are inadequate. In such a system, phytogeographic data are organized by dominants in climax communities, e.g., *Tsuga heterophylla*, *Abies lasiocarpa* and *Pinus ponderosa* without reference to zones, thereby avoiding the many difficulties posed by rugged mountain topography (Daubenmire 1968a).

Since we have elected to use zones, the reader should consider some attributes of the zonal scheme as he views the landscape:

1. Zones may occur as sequential belts on mountain slopes, but more often they interfinger, with each attaining its lower elevational limits in valleys and its highest limits on ridges; as a consequence, the zones along the slopes of a narrow valley can be reversed from their otherwise normal altitudinal relationship (Daubenmire 1946) (fig. 26).

[3] By definition, deep loamy soils and undulating topography constitute the zonal or modal habitat. In essence, neither soils nor topography significantly modify the macroclimatic factor in development of plant communities on these sites.

[4] In two cases we have named zones after major seral species characteristic of only that zone — *Picea sitchensis* and *Tsuga mertensiana*.

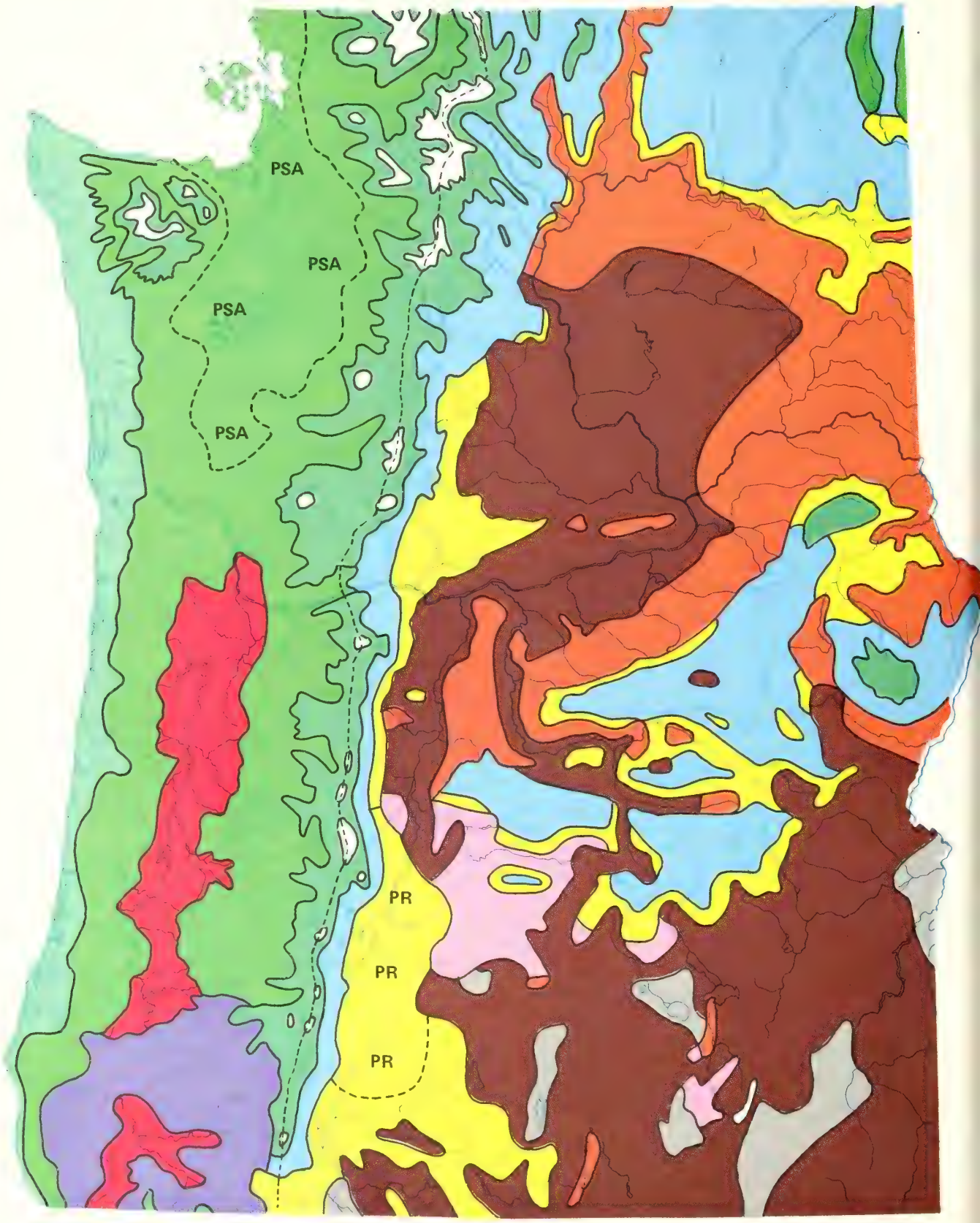


Figure 25. — Generalized vegetation map of Oregon and Washington (based partially on Hayes (1959), Küchler (1964), and Poulton (1962)).

LEGEND

FORESTED REGIONS

- *Picea sitchensis* Zone
- *Tsuga heterophylla* Zone
  - Puget Sound area (PSA)
- Mixed Conifer and Mixed Evergreen Zones
- Interior Valley Zone
- *Pinus ponderosa* Zone (broad sense)
  - Pumice region (PR)
- *Abies grandis* and *Pseudotsuga menziesii* Zones
- Subalpine forests (including *Abies amabilis, A. lasiocarpa, A. magnifica shastensis* and *Tsuga mertensiana* Zones)

STEPPE REGIONS

- STEPPE (without shrubs)
- SHRUB-STEPPE (*Artemisia* dominated)
- DESERT SHRUB
- *Juniperus occidentalis* Zone

TIMBERLINE AND ALPINE AREAS

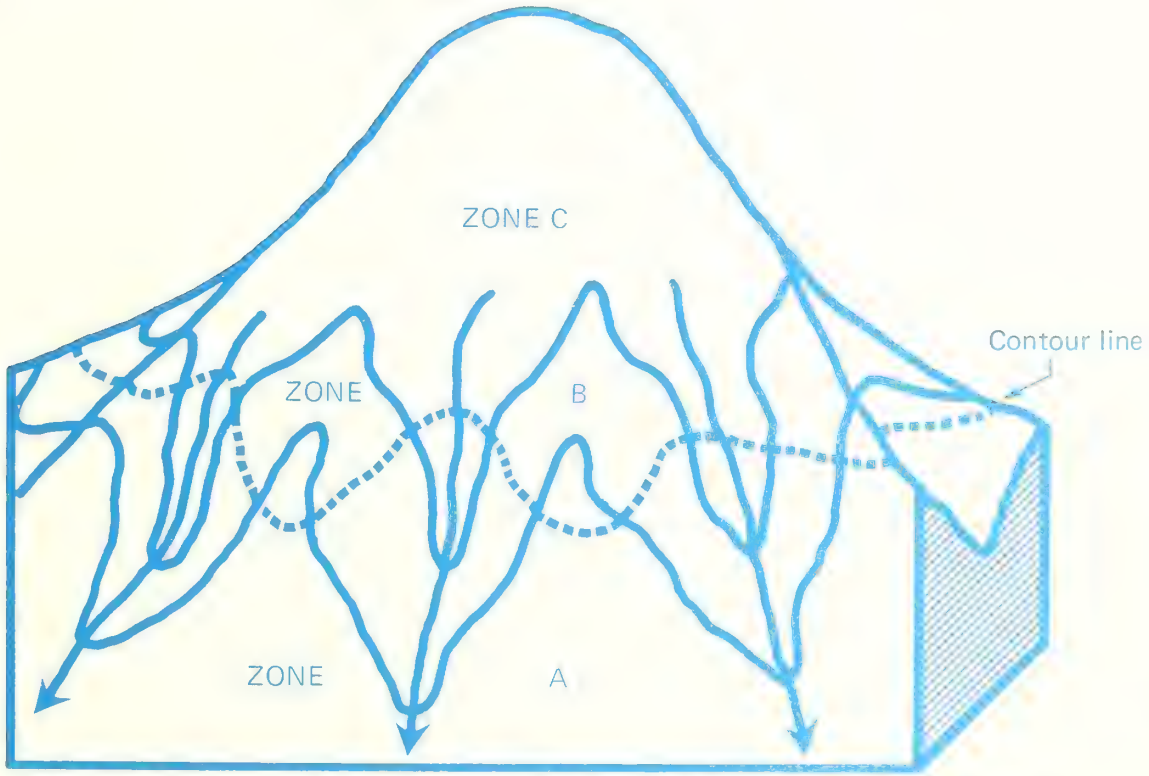


Figure 26. — Schematic diagram illustrating interfingering of zones in mountainous topography.

2. Related to this phenomenon is the tendency for species or associations, occupying modal sites in one zone, to occur on moist, cool habitats in the adjacent warmer and drier zone and on warm, dry habitats in the adjacent cooler and moister zone. For example, east of the Cascade crest, *Pseudotsuga menziesii* can occur as a climax species on relatively moist habitats in the *Pinus ponderosa* Zone or on relatively dry ridges within the *Abies grandis* Zone. In the Washington steppe, the zonal *Agropyron-Festuca* association may occur as a topographic climax on steep north slopes in the drier *Artemisia/Festuca* or on steep south slopes in the moister *Festuca/Symphoricarpos* Zone.
3. Disturbance and the resulting seral vegetation may obscure zonal sequences. Pioneer species often range through several vegetational zones. Many of the seral dominants in a given zone tend to be climax species in adjacent warmer and drier zones. Hence, *Pinus ponderosa* and *Pseudotsuga menziesii* are common pioneers on disturbed sites in the *Abies grandis* Zone. The relative abundance of understory and reproducing tree species often indicates trends in such areas.
4. Zonal schemes reflect plant responses to strong macroclimatic gradients in temperature and moisture. Unusual physical or chemical soil properties sometimes override climatic factors to severely modify zonation patterns. Serpentine areas and the pumice region east of Crater Lake, Oregon, are examples.

FORESTED REGIONS

In Oregon and Washington, forests dominate the landscapes west of the Cascade Range and the mountain slopes to the east (fig. 25). A great many tree species are endemic, but with rare exception the dominants are conifers. In fact, the finest coniferous forests in the world occur in this region and adjacent parts of California and British Columbia. Some of the major tree species are listed in table 3 along with data on their growth and longevity. The absence of major hardwood dominants in this region has often been noted (e.g., Küchler 1946); the dry summer climate has frequently been offered as an explanation. Their absence contrasts the forests of this region sharply with the mixed temperate forests of eastern United States.

The primarily forested areas can be divided into three major subregions: (1) western Washington and the Cascade and Coast Ranges of northern Oregon; (2) interior southwestern Oregon and the Willamette Valley, a relatively dry subregion with many Californian relationships; and (3) eastern Washington and Oregon (including the eastern slopes of the Cascade Range), an even drier and more continental subregion with affinities to the Rocky Mountain forests.

The zones in the three subregions can be related in terms of the factor primarily responsible for a given part of the zonal sequence (table 4). In the xerophytic zones, moisture is limiting for many species; each step up the zonal sequence indicates a more favorable moisture regime. Communities are very responsive to small differences in environment affecting plant moisture stresses (e.g., in exposure and soil depth). Within the temperate zones, neither moisture nor temperature conditions are severely limiting for the forest species. Forests grow and develop best in these zones, and species composition does not shift so markedly in response to local differences in site conditions. Temperature is the major factor separating subalpine types from temperate, with the related phenomenon of snowpack also profoundly influencing variation in community mosaics. Both factors appear limiting for many lower elevation species.

Western Washington and Northwestern Oregon

Western Washington and northwestern Oregon comprise the most densely forested region in the United States. At the time of the first settlers, conifer stands clothed almost the entire area from ocean shore to timberline.

Table 3. — Ages and dimensions typically attained by forest trees on better sites in the Pacific Northwest and their relative tolerances[1]

Species	Age	Diameter	Height	Tolerance[2]
	Years	Centimeters	Meters	
Abies amabilis	400+	90-110	45-55	VTOL
Abies concolor	300+	100-150	40-55	TOL
Abies grandis	300+	75-125	40-60	TOL
Abies lasiocarpa	250+	50-60	25-35	TOL
Abies magnifica	300+	100-125	40-50	INTER
Abies procera	400+	100-150	45-70	INTOL
Chamaecyparis lawsoniana	500+	120-180	60	TOL
Chamaecyparis nootkatensis	1,000+	100-150	30-40	TOL
Larix occidentalis	700+	140	50	INTOL
Libocedrus decurrens	500+	90-120	45	INTER
Picea engelmannii	500+	100+	45-50	TOL
Picea sitchensis	800+	180-230	70-75	TOL
Pinus contorta	250+	50	25-35	INTOL
Pinus lambertiana	400+	100-125	45-55	INTER
Pinus monticola	400+	110	60	INTER
Pinus ponderosa	600+	75-125	30-50	INTOL
Pseudotsuga menziesii	750+	150-220	70-80	INTOL
Sequoia sempervirens	1,000+	150-380	75-100	TOL
Thuja plicata	1,000+	150-300	60+	TOL
Tsuga heterophylla	400+	90-120	50-65	VTOL
Tsuga mertensiana	400+	75-100	25-35	TOL
Acer macrophyllum	300+	50	15	TOL
Alnus rubra	100	55-75	30-40	INTOL
Lithocarpus densiflorus	180	25-125	15-30	TOL
Populus trichocarpa	200+	75-90	25-35	INTOL
Quercus garryana	500	60-90	15-25	INTOL

[1] Developed from a variety of sources, the most important being Fowells (1965). Maximum ages and sizes for species are generally much greater than those indicated here.

[2] Tolerance scale: VTOL = very tolerant of shade, TOL = tolerant, INTER = intermediate shade tolerance (greater in youth, lesser at maturity), and INTOL = intolerant.

Table 4. — Forested zones in different parts of Oregon and Washington

Zonal groups	Interior southwestern Oregon	Eastern Washington and Oregon	Western Washington
Xerophytic	Interior Valley	*Juniperus occidentalis* *Pinus ponderosa* *Pseudotsuga menziesii*	([1])
	Mixed Evergreen		
Temperate	Mixed Conifer *Abies concolor*	*Abies grandis* *Tsuga heterophylla*	*Tsuga heterophylla* *Picea sitchensis*
			Abies amabilis
Subalpine	*Abies magnifica shastensis* *Tsuga mertensiana*	*Abies lasiocarpa*	*Tsuga mertensiana*

[1] There are xerophytic areas in the Puget Trough.

Presently, 82 percent of western Washington and Oregon is classed as forest land (Barrett 1962), a total of about 11,764,000 hectares.

Forests grow rapidly in this region; the size, density, and longevity of virgin old-growth stands are impressive (fig. 27). Dominant tree species typically reach heights of 50 to 75 meters at maturity (table 3). Many species often live beyond 500 years, a significant ecological feature. For example, in this area *Pseudotsuga menziesii* is mainly a pioneer or seral species that reproduces after fire or other disturbances. Its long life span enables it to persist during extended periods of stability and to reseed an area following the next disturbance.

Much forest land in western Washington and Oregon is occupied today by relatively young seral stands that have followed clearing, logging, and wildfire. Such stands are typically referred to as "second growth" regardless of origin. Clearing away the obstructing forest was, of course, the first order of business for settlers. Much of this cleared acreage has since been covered by towns, cities, and farms. The lumbering industry began almost simultaneously and grew rapidly in importance around the turn of the century. Activity was initially most intense in the lowlands of western Washington, but slowly shifted southward and higher into the mountains as the virgin forests were cut over. Carelessness, often associated with clearing and logging, has resulted in extensive fires during the dry warm summers and falls (fig. 28). Single burns usually reforest well from individual and/or grouped trees left by the fast-moving fires (fig. 29); repeatedly burned areas often remain treeless for many years (fig. 30).

At present, logging in the subregion is generally by clearcutting (Barrett 1962), partly for economic and partly for silvicultural reasons. *Pseudotsuga menziesii*, the preferred species, normally requires relatively open conditions for reproduction and rapid juvenile growth. In some areas, clearcuts are made as staggered patches (fig. 31), and in others, continuous clearcutting is practiced. Logging

Figure 27. — Old-growth *Pseudotsuga menziesii* stand, with abundant *Tsuga heterophylla* reproduction, typical of the dense coniferous forests clothing the Cascade and Coast Ranges in western Washington and northwestern Oregon.

Figure 28. — Wildfires of both natural and human origin have been responsible for the extensive seral forests of *Pseudotsuga menziesii*.

Figure 29. — Single wildfires typically leave individual trees or groups of trees which reforest the burned area quickly.

Figure 30. — Repeated wildfires can produce extensive tracts which remain deforested for decades without human intervention; Tillamook Burn, Oregon, first burned in 1933 and since reburned several times.

Figure 31. — Old-growth forests in western Washington and Oregon are typically logged in "staggered-setting" clearcuts of 15 to 30 hectares (Santiam River drainage, Willamette National Forest, Oregon).

slash is typically broadcast-burned after cutting and the site is seeded or planted, usually to *Pseudotsuga*.

Four vegetation zones can be recognized in western Washington and the Cascade and Coastal Ranges of northern Oregon: the coastal *Picea sitchensis* Zone, the very widespread *Tsuga heterophylla* Zone, *Abies amabilis* Zone, and the subalpine *Tsuga mertensiana* Zone. Typical tree species and their zonal occurrence in western Washington are listed in table 5.

"PICEA SITCHENSIS" ZONE

Picea sitchensis characterizes this long narrow zone which stretches the length of Washington and Oregon's coast. It is, in fact, just part of a coastal forest zone which extends north to Alaska and grades into *Sequoia sempervirens* forests in extreme southwestern Oregon. The *Picea sitchensis* Zone is generally only a few kilometers in width, except where it extends up river valleys. On the west side of the Olympic Peninsula, where an extensive coastal plain exists, it is much broader. Although the zone is generally found below elevations of 150 meters, it goes to 600 meters when mountain masses are immediately adjacent to the ocean. This zone could be considered a variant of the *Tsuga heterophylla* Zone distinguished by *P. sitchensis*, frequent summer fogs, and proximity to the ocean. Perhaps for this reason Krajina (1965) has not recognized a similar zone in British Columbia; our *Picea sitchensis* Zone is comparable to the Coastal Subzone of the Humid Transition Life Zone recognized by D. R. M. Scott (Barrett 1962).

Table 5. — Representative tree species and their relative importance in both seral and climax communities in forested zones of western Washington[1]

Species	Zones			
	Picea sitchensis	*Tsuga heterophylla*	*Abies amabilis*	*Tsuga mertensiana*
Abies amabilis	m	m	M	M
Abies grandis	m	m	m	—
Abies lasiocarpa	—	—	m	M
Abies procera	—	—	M	m
Chamaecyparis nootkatensis	—	—	m	M
Picea sitchensis	M	m	—	—
Pinus monticola	—	[2] m	m	m
Pinus contorta	m	[2] m	m	m
Pseudotsuga menziesii	M	M	M	m
Tsuga heterophylla	M	M	M	m
Acer macrophyllum	m	m	—	—
Alnus rubra	M	M	—	—
Thuja plicata	M	M	m	—

[1] M = major species, m = minor species.
[2] Except major species in the Puget Trough province.

Environmental Features

The *Picea sitchensis* Zone has what could be considered the mildest climate of any northwestern vegetation zone (table 6). Extremes in moisture and temperature regimes are minimal; the climate is uniformly wet and mild. Precipitation averages 2,000 to 3,000 millimeters, but frequent fog and low clouds during the relatively drier summer months are probably as important in ensuring minimal moisture stresses. Fog drip adds as much as 26 percent to annual precipitation (Ruth 1954). This is the consequence of condensation in tree crowns.

Some of the finest forest soils in the region are found in this zone — deep, relatively rich, and fine textured. Major great soil groups on upland forest sites are Brown Lateritics, Reddish Brown Lateritics, and Sols Bruns Acides. Surface soils are typically strongly acid (e.g., pH 5.0 to 5.5), high in organic matter (e.g., 15 to 20 percent) and total nitrogen (e.g., 0.50 percent), and low in base saturation (e.g., 10 percent).

Forest Composition

The coniferous forest stands in this zone are typically dense, tall, and productive (fig. 32). Constituent tree species are *Picea sitchensis*, *Tsuga heterophylla*, *Thuja plicata*, *Pseudotsuga menziesii*, *Abies grandis*, and *A. amabilis* (in Washington). The first three are by far the most common. *Alnus rubra* is one of the most abundant trees on recently disturbed sites,

Table 6. — Climatic data from representative weather stations within the *Picea sitchensis* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Quinault, Wash.	72	47°28′	123°51′	10.6	3.8	1.2	17.3	23.8	3,371	244	30
Astoria, Oreg.	66	46°11′	123°50′	10.6	4.7	2.1	16.0	20.6	1,967	140	--
Otis, Oreg.	49	45°02′	123°56′	10.3	5.3	2.2	15.3	20.9	2,496	163	--
Port Orford, Oreg.	96	42°44′	124°31′	11.3	7.9	4.3	14.9	19.2	1,780	81	--

Source: U. S. Weather Bureau (1956, 1965a, 1965b).

Figure 32. — A young, even-aged *Tsuga heterophylla* stand typical of the dense, productive forests found in the *Picea sitchensis* Zone.

Figure 33. — *Polystichum munitum* and *Oxalis oregana* dominate the understory of this *Picea sitchensis* stand; note the "prop" roots of the *Picea* which has developed on a rotting log (Neskowin Crest Research Natural Area, Siuslaw National Forest, Oregon).

and *Pinus contorta* is common along the ocean. *Sequoia sempervirens*, *Umbellularia californica*, and *Chamaecyparis lawsoniana* are found in this zone in southwestern Oregon.

Mature forests have lush understories with dense growths of shrubs, dicotyledonous herbs, ferns, and cryptogams (fig. 33). On sites modal in environmental conditions, *Polystichum munitum*, *Oxalis oregana*, *Maianthemum bifolium* var. *kamschaticum*, *Montia sibirica*, *Tiarella trifoliata*, *Viola sempervirens*, *V. glabella*, *Disporum smithii*, *Vaccinium parvifolium*, and *Menziesia ferruginea* are common understory species. On less favorable sites, e.g., old sand dunes and steep slopes facing the ocean, dense understories dominated by ericads such as *Gaultheria shallon*, *Rhododendron macrophyllum*, and *Vaccinium ovatum* are common. Wetter forested sites also have dense understories where *Oplopanax horridum*, *Athyrium filix-femina*, *Struthiopteris spicant*, *Dryopteris dilatata*, *Sambucus racemosa* var. *melanocarpa*, etc., are typical along with the "modal" site species mentioned earlier.

Cryptogams are extremely abundant and varied in the *Picea sitchensis* Zone — the so-called Olympic rain forest, noted for its mosses and liverworts (Sharpe 1956; Coleman et al. 1956; Harthill 1964), lies within this zone (fig. 34). Some common ground cryptogams are *Eurhynchium oreganum*, *Hylocomium splendons*, *Hypnum circinale*, *Rhytidiadelphus loreus*, *Mnium menziesii*, and *M. insigne*. *Isothecium spiculiferum*, *Ptilidium californicum*, *Porella navicularis*, and *Scapania bolanderi* are a small sample of the abundant epiphytes. *Alnus rubra* is an especially favorable host for epiphytic development (Pechanec and Franklin 1968; Coleman et al. 1956).

Successional Patterns

Early successional trends following fire or logging in the *Picea sitchensis* Zone are similar to those encountered in the *Tsuga heterophylla* Zone (see next section). There is a stronger tendency, however, toward development of dense shrub communities dominated by *Rubus spectabilis*, *Sambucus racemosa* var.

Figure 34. — Mosses and liverworts are abundant and varied in the forests of the wet *Picea sitchensis* Zone; epiphytes cover trees and shrubs in this Olympic "rain forest" (*photo courtesy Olympic National Park*).

melanocarpa, *Vaccinium* spp., etc., because of the favorable growing conditions.

There are two major kinds of seral forest stands in the zone: (1) conifer forest containing varying mixtures of *Picea*, *Tsuga*, and *Pseudotsuga*, and (2) *Alnus rubra* stands. *Alnus rubra* reproduces abundantly and grows extremely fast on disturbed forest land within the zone. In many cases, it overtops conifer regeneration, resulting in pure or nearly pure *Alnus* forest (fig. 35). Replacement of *A. rubra* by other tree species is often very slow, even though it is a relatively short-lived species. Successional sequences have not been thoroughly studied, although it appears that *Alnus rubra* can variously be replaced by semipermanent brushfields (Newton et al. 1968), by *Picea sitchensis* released from a suppressed state (Franklin and Pechanec 1968), or by *Thuja plicata* or *Tsuga heterophylla*, the latter often invading via down logs. *Alnus rubra* is noteworthy for its soil-improving properties; this species fixes significant amounts of nitrogen in this region (Tarrant 1968) and can have other effects on soil chemistry and microbiology as well (Franklin et al. 1968; Lu et al. 1968).

Figure 35. — The prolific and fast-growing *Alnus rubra* often pioneers on logged or burned lands in the *Picea sitchensis* Zone, offering severe competition for conifers; this typical 50-year-old *Alnus rubra* stand has an understory dominated by *Rubus spectabilis* (Siuslaw National Forest, Oregon).

Succession in most mature conifer forest types is toward replacement of mixed *Picea*, *Thuja*, *Tsuga*, and *Pseudotsuga* forests by *Tsuga heterophylla*. This species is apparently more tolerant than the *Picea sitchensis* and dominates the reproduction in old-growth forests. Since *P. sitchensis*, *Thuja plicata*, and *Pseudotsuga menziesii* are all long-lived species, even very old stands usually retain at least some of the original representation of these species. On moist to wet sites, it appears *T. plicata* and, in some cases, *P. sitchensis* will be at least a part of the climax along with *T. heterophylla*.

Much of the forest regeneration in conifer stands takes place on rotting logs, "nurse logs," which often support hundreds of *Tsuga*, *Picea*, and *Thuja* seedlings (fig. 36) (Sharpe 1956). Some of these survive, and their roots eventually reach mineral soil. The consequences are often readily visible in forests as lines of mature trees growing along the remains of the original nurse logs.

Special Types

Including, as it does, the ocean strand, headland, and coastal plain environments, the *Picea sitchensis* Zone is the locale of a rich variety of specialized communities.

Sand dune and strand communities. — Sand dunes are the major locale where ocean-facing vegetation types have been studied by ecologists. In Oregon and Washington, there are extensive areas of such dunes — on 225 kilometers of 500 kilometers of shoreline in Oregon alone (Wiedemann 1966) (fig. 37). The greatest development is the Coos Bay dune sheet covering 86 kilometers of continuous coastline and a major site of Cooper's (1958) monumental study of dune origin and form.

Some features of shoreline vegetation are immediately obvious — e.g., communities of sand colonizers and stabilizers, the often impenetrable, bordering belts of shrubs and forests of *Pinus contorta* and *Picea sitchensis*. Strong, seashore winds greatly influence composition and form of the vegetation by desiccating foliage, transporting salt spray, and abrading the plants with sand. As a conse-

Figure 36. — *Tsuga, Picea,* and *Thuja* seedlings developing on a rotting nurse log, a typical phenomenon in forests of the *Picea sitchensis* Zone (Quinault Research Natural Area, Olympic National Forest, Washington); the range pole in this and other photos, unless otherwise noted, is 1 m. in height and marked in dm. segments.

Figure 37. — Sand dunes are very extensive along the Oregon coast, occupying nearly half the 500 kilometers of shoreline; pictured is the north end of the Coos Bay dune sheet, the most extensive single area of dune development in the Northwest (*photo courtesy Siuslaw National Forest*).

quence, the stands of *Pinus contorta* and *Picea sitchensis* are frequently deformed on the oceanside and increase in height to the lee (fig. 38). Also obvious in some localities are the plant communities, even whole forest stands, being engulfed by moving sand dunes (fig. 39).

Dune and strand vegetation of the Oregon coast has been studied by many scientists, including Egier (1934), Green (1965), Byrd (1950), Hanneson (1962), Kumler (1963), and Wiedemann (1966). Any discussion should probably begin with the early plant colonizers which begin sand stabilization. Some of the more important species are *Glehnia leiocarpa, Carex macrocephala, Franseria chamissonis, Abronia latifolia, Convolvulus soldanella, Lupinus littoralis, Poa macrantha, Polygonum paronychia, Juncus lesueurii* and *falcatus, Potentilla anserina, Calamagrostis nutkaensis, Elymus mollis, Plantago maritima,* and *Cotula coronopifolia* (Heusser 1960, Kumler 1963). *Ammophila arenaria* is an important pioneer deserving special mention. It was first introduced in the late 1800's for use in dune control planting on the Oregon coast

Figure 38. — Ocean winds and spray strongly influence form and composition of beach-bordering communities; *Picea sitchensis* at Cape Perpetua, Oregon (*photo courtesy Siuslaw National Forest*).

Figure 39. — Active or moving sand dune burying a coastal stand of *Pinus contorta* (Siuslaw National Forest, Oregon).

(Green 1965). Since that time, it has become naturalized and occurs widely, especially along the immediate shoreline (next to the high tide line). In fact, *Ammophila arenaria* is responsible for development of foredunes along portions of the coast, a dune type relatively uncommon prior to 1930 (Wiedemann 1966).

The shrub communities are often extremely dense and 1 to 3 meters in height. The most constant element is apparently *Gaultheria shallon* (Heusser 1960, Kumler 1963, Wiedemann 1966). Other species typically present are *Vaccinium ovatum*, *Myrica californica*, *Rhododendron macrophyllum*, *Arctostaphylos uva-ursi*, *Rubus spectabilis*, and *Arctostaphylos columbiana*. Shrub stands on wetter sites (e.g., deflation plains) may include *Salix hookeriana*, *Alnus rubra*, *Ledum glandulosum* var. *columbianum*, *Spiraea douglasii* and *Lonicera involucrata* (Wiedemann 1966). *Pinus contorta* and *Picea sitchensis* seedlings are frequently present.

The forest stands on sand dunes are typically composed of *Pinus contorta* or *Picea sitchensis* or both. *Pseudotsuga menziesii*, *Thuja plicata*, or even *Tsuga heterophylla* (in later stages of development) may occasionally be present but are not typical. In southern Oregon, *Chamaecyparis lawsoniana* can be a pioneer forest species. It appears that *Pinus contorta* is seral on most (but not all) sand dune sites (Wiedemann 1966).

Wiedemann (1966) conducted the most comprehensive study of succession on Oregon sand dunes. He concentrated on deflation plains, areas where moist sand near the water table has been exposed, effectively stopping sand movement. Earliest stages in succession are herbaceous communities which differ compositionally, depending on moisture conditions: dry meadow, meadow, rush meadow,

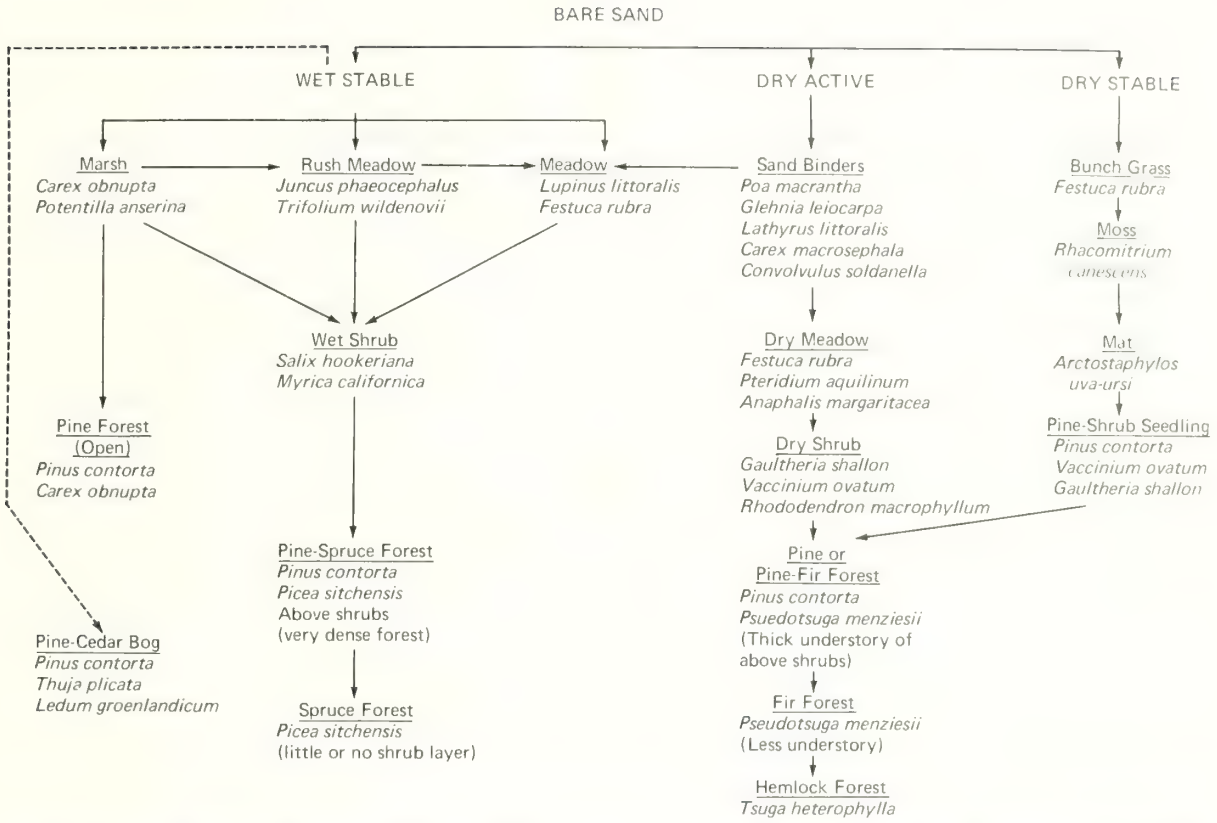


Figure 40. — Plant succession on Oregon coastal sand dunes (from Wiedemann (1966) with later modifications by Wiedemann).

and marsh. Major species in these communities are:

Community	Species
Dry Meadow	*Lupinus littoralis, Ammophila arenaria, Poa macrantha, Festuca rubra*
Meadow	*Festuca rubra, Lupinus littoralis, Aira praecox, Hypochaeris radicata, Fragaria chiloensis*
Rush Meadow	*Trifolium willdenovii, Juncus phaeocephalus* and *falcatus, Aster subspicatus, Sisyrinchium californicum*
Marsh	*Carex obnupta, Potentilla anserina, Hypericum anagalloides, Ranunculus flammula, Lilaeopsis occidentalis*

A wet shrub community can develop directly from any of the last three communities and is followed, in turn, by forests of *Pinus contorta* and *Picea sitchensis*. Some exceptions to this general outline include: open *Pinus contorta/Carex obnupta* forests and forest bogs of *Pinus contorta, Thuja plicata, Ledum groenlandicum, Darlingtonia californica, Lysichitum americanum*, and *Struthiopteris spicant*. Successional sequences on deflation plains and areas of dry active and inactive sand are schematically illustrated in fig. 40.

On the southern Oregon coast (from Coquille south), the coastline vegetation differs significantly (Heusser 1960, Peck 1961). The shrub and forest stands of *Gaultheria shallon, Pinus contorta*, and *Picea sitchensis* are absent. In their place (above the beach) are communities of herbs and low shrubs grading into a zone of taller shrubs. Typical species on the exposed seaward slopes are *Juniperus communis, Zygadenus fremontii, Mesembryanthemum chilense, Eriogonum latifolium, Sidalcea malvaeflora, Plantago subnuda, Agoseris hir-*

Figure 41. — Herbaceous communities occupy exposed portions of many headlands along the Oregon coast as shown here at Heceta Head (*photo courtesy Siuslaw National Forest*).

suta, *Scirpus setaceus*, *Brodiaea coronaria* var. *macropoda*, and *Iris douglasiana* var. *oregonensis*. The shrub zone is dominated by *Ceanothus thyrsiflorus*, *Garrya elliptica*, *Rhododendron occidentale*, *Alnus sinuata*, *Ribes menziesii*, and *Arctostaphylos columbiana* (Heusser 1960, Peck 1961, Gratkowski 1961a). *Ulex europaeus*, an introduced shrub, is an important weed species along the southern coast where it creates impenetrable thickets and a serious fire hazard (Wiedemann 1966, Gratkowski 1961a).

Tidal marshes. — The marsh communities on tidal flats are relatively unknown. Peck (1961) lists the following species as those most characteristic along Oregon's northern coast: *Triglochin maritima*, *Distichlis spicata*, *Puccinellia pumila*, *Scirpus americanus*, *S. pacificus*, *Juncus effusus*, *J. balticus*, *Salicornia pacifica*, *Glaux maritima*, *Cuscuta salina*, *Grindelia stricta*, and *Jaumea carnosa*. Heusser (1960) mentions that *Distichlis spicata* and *Salicornia pacifica* are codominants on tidal flats on the east side of the Olympic Peninsula. Johannessen (1964) studied prograding tidal marsh at Nehalem Bay in Oregon. He found *Triglochin maritima* was typical of the lowest habitats, near deep river channels. Higher and broader expanses of mud flats were dominated by *Scirpus pacificus* and *Carex lyngbyei* and those farther inland, by *Deschampsia caespitosa* and *Juncus balticus*. Muenscher (1941) has provided species lists for salt marshes and tidal flats along Puget Sound in Whatcom County, Washington.

Prairies. — Prairies, treeless areas in an otherwise heavily forested locale, are scattered through the *Picea sitchensis* Zone (fig. 41). These have been studied in only two locales: a fern-dominated prairie on the coastal plain of the western Olympic Peninsula (Lotspeich et al. 1961) and a grassy headland prairie on the Oregon coast (Davidson 1967). Fortunately, both are representative of widespread prairie "types." Both of these prairies are surrounded by *Picea sitchensis* and *Tsuga heterophylla* forest.

The Quillayute Prairie (Lotspeich et al. 1961) is dominated by *Pteridium aquilinum* var. *pubescens;* other common species are *Achillea millefolium*, *Anthoxanthum odoratum*, *Eriophyllum lanatum*, *Fragaria vesca* var. *bracteata*, *Holcus lanatus*, *Hypericum perforatum*, *Prunella vulgaris* var. *lanceolata*, and *Spiraea douglasii* var. *menziesii*. Encroachment of the forest on this prairie was believed to be extremely slow prior to human disturbance. Rapid invasion of the prairie by *Picea sitchensis* has followed plowing, burning, or grazing of the original vegetation.

Davidson (1967) recognized five communities on a 10-acre headland prairie. The *Polystichum munitum-Rubus parviflorus*, *Artemisia suksdorfii-Solidago canadensis*, and *Solidago canadensis* communities were most important. *Pteridium aquilinum* was present in most stands, but not a dominant. Notable species in one or more communities besides the aforementioned were: *Equisetum maximum*, *Ranunculus occidentalis*, *Heracleum lanatum*, *Stachys mexicana*, *Galium aparine*, *Marah oregana*, *Rubus spectabilis*, *Angelica lucida*, *Carex obnupta*, *Lupinus littoralis*, *Achillea millefolium*, *Plantago lanceolata*, *Holcus lanatus*, *Agrostis tenuis*, *Elymus glaucus*, *Anthoxanthum odoratum*, *Festuca rubra*, *Dactylis glomerata*, *Bromus sitchensis*, and *Rosa nutkana*. Gradual invasion of the prairie by *Picea sitchensis* appears to be taking place, primarily along trees which have fallen into the prairie and become nurse logs.

Forested swamps. — Cedar and alder swamps are another specialized series of communities which are probably more common in the *Picea sitchensis* Zone than in any other. Swamps of this type are found in the *Tsuga*

heterophylla Zone as well, and even, occasionally, in the *Abies amabilis* Zone. However, they are most common on the coastal plains and portions of glacial drift adjacent to Puget Sound. The constant habitat characteristic is a high water table, or even standing surface water, for all or a portion of the year.

The chief tree species on these sites are *Thuja plicata* or *Alnus rubra* or both. In fact, it is in some of these swamp communities that *A. rubra* appears to be a climax species. *Picea sitchensis*, *Pinus contorta*, and *Tsuga heterophylla* may also be present. Although the understory is often dominated by only one or two species, such as *Lysichitum americanum* or *Carex obnupta*, a great variety of shrubby or herbaceous species may be present. Some of the more characteristic are *Struthiopteris spicant*, *Athyrium filix-femina*, *Oenanthe sarmentosa*, *Stachys mexicana*, *Mitella* spp., *Tolmiea menziesii*, *Spiraea douglasii*, *Salix hookeriana*, and *Rubus spectabilis*.

"TSUGA HETEROPHYLLA" ZONE

The *Tsuga heterophylla* Zone is the most extensive vegetation zone in western Washington and Oregon and the most important in terms of timber production. This is the region famous for subclimax *Pseudotsuga menziesii* and climax *Tsuga heterophylla-Thuja plicata* formations (Weaver and Clements 1938; Oosting 1956; Cooper 1957). The *Tsuga heterophylla* Zone extends south from British Columbia through the Olympic Peninsula, Coast Ranges, Puget Trough, and both Cascade physiographic provinces in western Washington (fig. 25). In Oregon, it is split into two major segments — located in the Coast Ranges and in the Western and High Cascades provinces — by the Willamette and other dry interior valleys. The southern limits are the Klamath Mountains on the coast (except for a narrow coastal strip) and the divide between the North and South Umpqua Rivers in the Cascade Range (about 43°15′ N. lat.). Elevational range in the Cascade Range varies from essentially sea level to 600 or 700 meters at 49° north latitude and from 150 to 1,000 meters at 45° north latitude. In the Olympic Mountains, the *Tsuga heterophylla* Zone occurs between 150 and 550 meters on the western

Figure 42. — *Pseudotsuga menziesii* is often the sole dominant tree in forests of the *Tsuga heterophylla* Zone, even in old-growth stands, although it is almost invariably seral (along Cave Creek, Gifford Pinchot National Forest, Washington).

slopes and from nearly sea level to 1,125 meters on the drier eastern slopes (Fonda 1967). Where conditions are favorable, elements of this zone appear on the east side of the Cascade Range (discussed later in this paper) and in the northern Rocky Mountains (Daubenmire 1952; Daubenmire and Daubenmire 1968).

The *Tsuga heterophylla* Zone as recognized here is analagous to Krajina's (1965) Coastal Western Hemlock Zone, except for our separation of the coastal *Picea sitchensis* Zone. In western Washington, it is essentially in agreement with Scott's definition of Merriam's Humid Transition Zone (Barrett 1962); however, in southwestern Oregon, the *Tsuga het-*

erophylla Zone does not include much of the area considered Humid Transition Zone.

It is emphasized that although this is called the *Tsuga heterophylla* Zone, based on the potential climax species, large areas are dominated by forests of *Pseudotsuga menziesii.* Much of the zone has been logged or burned, or both, during the last 150 years, and *Pseudotsuga* is usually a dominant (often a sole dominant) in the seral stands which have developed (Munger 1930, 1940). Even old-growth stands (typically 400 to 600 years old) frequently retain a major component of *Pseudotsuga* (fig. 42).

Environmental Features

The *Tsuga heterophylla* Zone has a wet, mild, maritime climate (table 7). Since the zone lies farther from the ocean, moisture and temperature extremes are greater than in the *Picea sitchensis* Zone. Also, there is a great deal of climatic variation in this widespread zone associated with latitude, elevation, and location in relation to mountain massifs. Precipitation averages 1,500 to 3,000 millimeters and occurs mainly during the winter; Orloci (1965) has suggested 1,650 centimeters precipitation is the lower limit of the Coastal Western Hemlock Zone in British Columbia. Summers are relatively dry with only 6 to 9 percent of the total precipitation. Moisture stresses are sufficient to result in distinctive community spectra along moisture gradients (McMinn 1960). Mean annual temperatures average 8° to 9° C., and neither January nor July temperatures are extreme (table 7).

Despite the fact soils in the *Tsuga heterophylla* Zone are derived from a wide variety of parent rocks, they tend to have some general features in common. Soil profiles are generally at least moderately deep and of medium acidity. Surface horizons are well aggregated and porous. Organic matter content ranges from moderate in the Cascades to high in portions of the Coast Ranges and Olympic Peninsula, where thick, very dark A1 horizons are especially common. Forest floor depths are generally less than 7 centimeters, except at higher elevations where they may reach 15 centimeters in thickness. Depending on degree of profile development, amounts of clay accumulation in the B horizon vary from low to medium. Most soils in the zone are of medium texture, ranging from sandy loam to clay loam. In many areas, zonal soils are limited to moderate slope positions, but on the steeper slopes poorly developed Regosols and Lithosols are encountered most often. Great soil groups, characteristic of the *Tsuga heterophylla* Zone, include Sols Bruns Acides and Reddish Brown Lateritic soils in the Coast Ranges and Olympic Peninsula provinces, and Brown Podzolic soils as well as Reddish Brown Lateritic in the Cascade Range.

Forest Composition

Major forest tree species in this zone are *Pseudotsuga menziesii, Tsuga heterophylla,* and *Thuja plicata. Abies grandis, Picea sitchensis* (near the coast), and *Pinus monticola* occur sporadically. Both *Pinus monticola* and *Pinus contorta* are common on glacial drift in the Puget Sound area. In Oregon, especially near the southern limits of the zone, *Libocedrus decurrens, Pinus lambertiana,* or even *Pinus ponderosa,* may be encountered. *Abies amabilis* is common near the upper altitudinal limits or even well within the *Tsuga heterophylla* Zone in the northern Cascade Range and Olympic Mountains. *Chamaecyparis lawsoniana* is a major element of the forests in a portion of the southern Oregon Coast Ranges. *Taxus brevifolia* is found throughout the zone, but always as a subordinant tree.

Hardwoods are not common in forests of the *Tsuga heterophylla* Zone and, except on recently disturbed sites or specialized habitats (e.g., riparian sites), are almost always subordinant. *Alnus rubra, Acer macrophyllum,* and *Castanopsis chrysophylla* are the most widespread. *Populus trichocarpa* and *Fraxinus latifolia* with *Acer macrophyllum* and *Alnus rubra* are found along major water courses. *Arbutus menziesii* and *Quercus garryana* may be found on drier, lower elevation sites anywhere in the zone, but are not characteristic. *Umbellularia californica* and *Lithocarpus densiflorus* are found in the southern Oregon Coast Ranges.

The forest communities of the *Tsuga heterophylla* Zone have been studied in detail at many locations. Excluding strictly succession-

Table 7. — Climatic data from representative stations within the *Tsuga heterophylla* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Darrington, Wash.	168	48°15′	121°36′	9.7	1.0	−3.3	17.4	25.7	2,045	154	120
Greenwater, Wash.	521	47°09′	121°39′	7.4	−1.2	−3.7	15.8	22.6	1,487	138	198
Castle Rock, Wash.	36	46°17′	122°54′	10.4	2.9	−.2	17.6	26.7	1,453	109	27
Wind River, Wash.	351	45°48′	121°56′	8.8	0	−3.7	17.5	26.9	2,528	119	233
Detroit, Oreg.	485	44°44′	122°09′	9.3	.9	−3.2	17.9	27.5	1,929	110	156
McKenzie Bridge, Oreg.	419	44°10′	122°10′	10.1	1.6	−2.6	18.9	29.4	1,789	106	--
Valsetz, Oreg.	346	44°50′	123°40′	9.6	2.4	−.7	16.6	25.6	3,207	144	38

Source: U. S. Weather Bureau (1956, 1965a, 1965b).

Table 8. — Abundance of selected species in three associations found in the *Tsuga heterophylla* Zone of the western Oregon Cascade Range

Species	Association		
	Pseudotsuga /Holodiscus	*Tsuga/ Berberis*	*Tsuga/ Polystichum*
Trees			
Pseudotsuga menziesii	Abundant	Common	Occasional
Tsuga heterophylla	Rare	Common	Common
Thuja plicata	--	Occasional	Common
Acer macrophyllum	Occasional	-	Rare
Libocedrus decurrens	Occasional	--	--
Pinus lambertiana	Occasional	--	--
Arbutus menziesii	Rare	--	--
Taxus brevifolia	Common	Common	Occasional
Shrubs			
Acer circinatum	Common	Common	Occasional
Holodiscus discolor	Common	--	--
Gaultheria shallon	Abundant	Occasional	Rare
Corylus cornuta californica	Common	--	Rare
Vaccinium parvifolium	Common	Common	Common
Rhododendron macrophyllum	Rare	Common	Rare
Symphoricarpos mollis	Common	Rare	Rare
Berberis nervosa	Common	Common	Common
Rubus ursinus	Common	Common	Common
Herbs			
Linnaea borealis	Common	Common	Occasional
Whipplea modesta	Common	Rare	--
Synthyris reniformis	Common	Rare	--
Polystichum munitum	Rare	Occasional	Abundant
Coptis laciniata	Rare	Common	Occasional
Viola sempervirens	Occasional	Common	Occasional
Vancouveria hexandra	Rare	Rare	Common
Tiarella trifoliata	--	Rare	Common
Disporum smithii	--	--	Occasional
Trillium ovatum	Occasional	Occasional	Occasional
Hieracium albiflorum	Common	Rare	--
Galium triflorum	--	Occasional	Common
Oxalis oregana	--	Rare	Common
Struthiopteris spicant	--	--	Occasional
Asarum caudatum	-	--	Occasional
Festuca occidentalis	Common	-	--
Iris tenax	Common	--	--
Mosses, Liverworts and Lichens			
Eurhynchium oreganum	Occasional	Abundant	Common
Homalothecium megaptilum	Occasional	Occasional	Rare
Hylcomium splendens	Occasional	Rare	Occasional
Rhytidiadelphus loreus	Common	Occasional	Occasional
Rhacomitrium canescens	Occasional	--	-
Mnium insigne	-		Common
Peltigera aphthosa	Common	--	--
Dicranum fuscescens	Common	Common	Occasional
Hypnum circinale	Common	Common	Common
Cladonia spp.	Occasional	Rare	--
Scapania spp.		Rare	Occasional

Source: Unpublished data on file at Forestry Sciences Laboratory, Pacific Northwest Forest & Range Exp. Sta., Forest Serv., U. S. Dep. Agr., Corvallis, Oregon.

al studies, these include (1) community classifications of seral *Pseudotsuga menziesii* stands (Spilsbury and Smith 1947; Becking 1954, 1956), (2) community descriptions for limited areas (Dirks-Edmunds 1947; Macnab 1958; Neiland 1958; Merkle 1951; Anderson 1967), and (3) investigations of the entire spectrum of forest communities (Bailey 1966; Orloci 1965; Corliss and Dyrness 1965; Rothacher et al. 1967; and Fonda 1967). Bailey and Poulton (1968) and Mueller-Dombois (1965) concentrated upon seral communities, McMinn (1960) upon community-moisture relationships, and Eis (1962) upon community correlations with environment and productivity. Cryptogamic components of forests in the *Tsuga heterophylla* Zone have been reported by Pechanec (1961), Higinbotham and Higinbotham (1954), Spilsbury and Smith (1947), Orloci (1965), and Becking (1954).

Significantly, the more comprehensive studies have shown a similar spectrum of communities arranged along moisture gradients. For example, on dry sites, understories are characterized by *Holodiscus discolor* or *Gaultheria shallon*, or both. On mesic sites, *Berberis nervosa* and *Acer circinatum* are often used as character species. *Polystichum munitum* and *Oxalis oregana* are typical of moister sites. *Lysichitum americanum* typifies the wettest forested sites. Although the details of community composition and nomenclature vary with the investigator and the locale, this same basic pattern — *Gaultheria-Berberis-Polystichum* — is repeated throughout the *Tsuga heterophylla* Zone.

Three old-growth community types are representative of this spectrum on the western slopes of Oregon's Cascade Range (about 45° N. lat.).[5] These community types are tentatively designated the *Pseudotsuga menziesii/Holodiscus discolor*, *Tsuga heterophylla/Berberis nervosa*, and *Tsuga heterophylla/Polystichum munitum* associations. Some compositional data for these associations are listed in table 8. Although these data are from old-growth communities, the same types of understories are found in much younger forests, including seral stands dominated completely by *Pseudotsuga menziesii* (see, e.g., Spilsbury and Smith 1947).

Figure 43. — A *Pseudotsuga menziesii/Holodiscus discolor* community typical of dry forest sites in the *Tsuga heterophylla* Zone; note the open nature of the stand and reproduction of *Pseudotsuga*, which is climax here (H. J. Andrews Experimental Forest, Oregon).

The *Pseudotsuga menziesii/Holodiscus discolor* association typifies the driest forested sites. The overstory is relatively open (fig. 43) and consists primarily of *Pseudotsuga menziesii*, although species such as *Libocedrus decurrens*, *Arbutus menziesii*, and *Acer macrophyllum* are often present. All age classes of *Pseudotsuga* from seedlings to veterans are present in these stands (fig. 43), indicating it appears as the major climax species. *Holodiscus discolor*, *Corylus cornuta* var. *californica*, *Symphoricarpos mollis*, and *Gaultheria shallon* typify the shrub layer. A number of herbs not common on mesic sites find their forest optimum here; e.g., *Synthyris reniformis*, *Whipplea modesta*, *Hieracium albiflorum*, *Festuca occidentalis*, and *Iris tenax*. Similar communities are much more common outside the *Tsuga heterophylla* Zone; e.g., in southwestern Oregon.

[5] Source materials for this discussion are unpublished data on file at Forestry Sciences Laboratory, Pacific Northwest Forest & Range Exp. Sta., Forest Serv., U. S. Dep. Agr., Corvallis, Oregon.

Figure 44. — An understory characterized by *Berberis nervosa* typifies modal sites in the *Tsuga heterophylla* Zone; a *Pseudotsuga menziesii-Tsuga heterophylla/Berberis nervosa* community in western Oregon (H. J. Andrews Experimental Forest).

Figure 45. — *Polystichum munitum* dominates the lush herbaceous understory on moist sites in the *Tsuga heterophylla* Zone (H. J. Andrews Experimental Forest, Oregon).

The *Tsuga heterophylla/Berberis nervosa* association and its relatives typify the climatic climax for the *Tsuga heterophylla* Zone (fig. 44). Old-growth stands consist primarily of *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Thuja plicata*. *Tsuga heterophylla* is, theoretically, the sole climax species based on size-class analyses. However, long-lived *Pseudotsuga menziesii* and *Thuja plicata* are often present in stands undisturbed for 500 years or more.

The understory is generally balanced between layers in the *Tsuga/Berberis* association. Major shrubs are *Berberis nervosa*, *Acer circinatum*, *Vaccinium parvifolium*, *Rubus ursinus*, and *Rhododendron macrophyllum*. Typical herbs are *Linnaea borealis*, *Viola sempervirens*, *Coptis laciniata*, and *Goodyera oblongifolia*. The most common moss is *Eurhynchium oreganum*. *Polystichum munitum* and *Gaultheria shallon* are often present, but not as understory dominants.

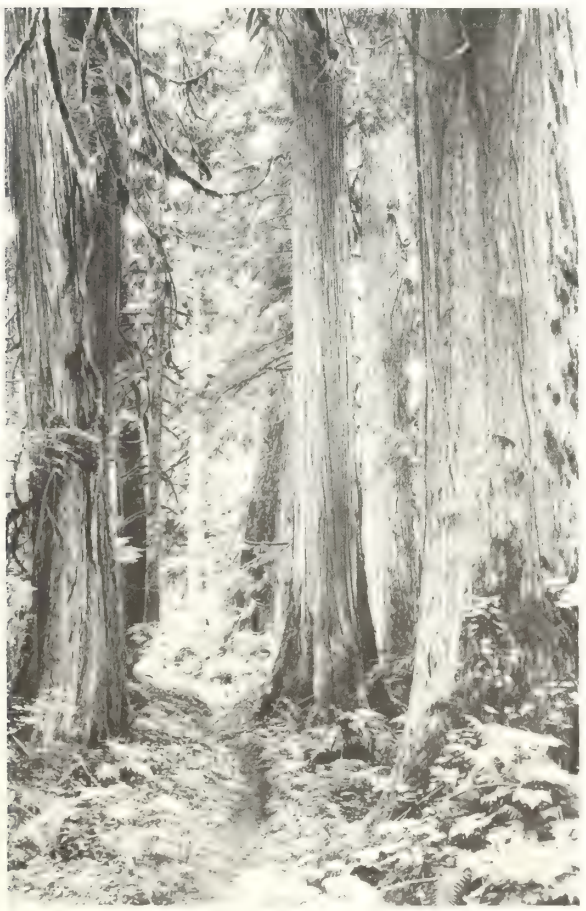
The *Tsuga heterophylla/Polystichum munitum* association characterizes the herb-rich communities found on moister habitats. The overstory usually includes *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Thuja plicata*. Very large *Pseudotsuga* are encountered in old-growth stands, as growth conditions are near optimum for the species. Size-class analyses indicate *Tsuga heterophylla* will be the major climax species, but *Thuja plicata* also reproduces in sufficient quantity to perpetuate itself. The understory is dominated by a lush growth of herbs (fig. 45), including *Polystichum munitum*, *Oxalis oregana*, *Tiarella trifoliata*, *Dryopteris* spp., *Galium triflorum*, *Disporum smithii*, *Struthiopteris spicant*, *Asarum caudatum*, and *Vancouveria hexandra*. Mosses and liverworts are also common, including *Eurhynchium oreganum*, *Mnium* spp., and *Scapania* spp.

Communities typifying the wet to very wet end of the moisture scale are not common in the Oregon Cascade Range. They are frequently encountered in the *Tsuga heterophylla* Zone in western Washington. One typical community found on lower slopes and stream terraces has extremely lush understory shrubs, dicotyledonous herbs, and ferns (fig. 46). *Pseudotsuga menziesii* and *Tsuga heterophylla* may be present, but *Thuja plicata* is invariably the conspicuous tree (fig. 46). Dominants include *Oplopanax horridum*, *Athyrium filix-femina*, *Struthiopteris spicant*, *Vaccinium* spp., *Dryopteris linnaeana* and *D. spinulosa* var. *dilatata*, *Trautvetteria caroliniensis*, *Anemone deltoidea*, *Viola glabella*, *Streptopus* spp., *Smilacina* spp., *Tiarella trifoliata*, and *Achlys triphylla*. Another community, found on swampy sites, is typified by *Thuja plicata* and *Lysichitum americanum* plus a wide variety of semiaquatic species.

There are many variations of this general community spectrum throughout the *Tsuga heterophylla* Zone. There is a general response to decreasing moisture (or, conversely, increasing moisture stress) from north to south, for example. In Washington, sites sufficiently dry to develop the *Pseudotsuga/Holodiscus*

community are relatively rare. Instead, *Pseudotsuga menziesii/Gaultheria shallon* community, in which *Tsuga heterophylla* is the probable climax, is usually found on the poorest quality sites. Similarly, communities with *Polystichum*-type understories are more widespread in Washington. There is a rather regular increase of *Pseudotsuga* importance from north to south within the zone, given stands of similar age. A notable difference between communities described in Oregon and in Washington is in the importance of *Rhododendron macrophyllum*. In many *Tsuga*-zone communities in Oregon, *Rhododendron macrophyllum* is a dominant; in Washington, it occurs sporadically.

Figure 46. — ***Thuja plicata* and dense understories of shrubs and herbs, such as *Oplopanax horridum* and *Athyrium filix-femina*, are typical of old-growth stands on wet benches and stream terraces in the *Tsuga heterophylla* Zone (Mount Baker National Forest, Washington).**



Successional Patterns

The early stages of secondary succession following logging and burning in this zone have been the subject of a number of studies. Unfortunately, however, much of this research has been limited to the first 5 to 8 years after complete tree removal, and, therefore, detailed successional patterns for the entire period of forest reestablishment have not been worked out. Timber harvesting operations in the *Tsuga heterophylla* Zone generally involve clearcut logging, followed by controlled burning of the logging slash to reduce wildfire hazard. During the first growing season after burning, the sparse plant cover is made up of residual species from the original stand, plus small amounts of invading herbaceous species such as *Senecio sylvaticus*, *Epilobium angustifolium*, and *E. paniculatum* (fig. 47) (Dyrness 1965). A moss-liverwort stage has also been noted during the first year (Isaac 1940; Ingram 1931).

Vegetation the second year is dominated by invading annual herbaceous species, species which produce large numbers of small, windborne seeds (fig. 47). Over much of the zone, a very high proportion of the second-year cover is made up of *Senecio sylvaticus*, a species which is present in only very small amounts in subsequent years (Brown 1963; Isaac 1940). West and Chilcote (1968) have shown this short-term dominance is related to high nutrient requirements which are generally satisfied only on recently burned sites. Perennial invading herbaceous species, such as *Epilobium angustifolium*, *Cirsium vulgare*, and *Pteridium aquilinum*, rapidly build up their populations until the fourth or fifth year when their rate of increase slackens (fig. 47) (Ingram 1931; Isaac 1940; Yerkes 1960).

This successional stage, sometimes called the weed stage, gradually gives way to a shrub-dominated period (fig. 48). These shrubs, including residual species such as *Acer circinatum*, *Rubus ursinus*, *Berberis nervosa*, *Rhododendron macrophyllum*, and *Gaultheria shallon*, as well as invaders such as *Ceanothus velutinus* and *Salix* spp., then dominate the site until they are overtopped by tree saplings, generally *Pseudotsuga menziesii* (Kienholz 1929; Ingram 1931; Isaac 1940).

Figure 47. — Herbaceous stages in secondary succession in the *Tsuga heterophylla* Zone; range pole is 4 feet tall and marked in 6-inch segments.

A. Virtually bare condition during the first growing season following slash burning.

B. The second year after slash burning, invading *Senecio sylvaticus* dominates the site.

C. During the third year, *Epilobium angustifolium* replaces *Senecio*, which has almost completely dropped out of the stand.

D. By the fifth growing season after slash burning, the invading shrub, *Ceanothus velutinus*, is beginning to gain dominance over the herbaceous invaders (here, mainly *Epilobium angustifolium* and *E. paniculatum*). (H. J. Andrews Experimental Forest, Oregon)

Herbaceous species surviving from the original forest stand (e.g., *Polystichum munitum*, *Trientalis latifolia*, and *Oxalis oregana)* are reported to be of only minor importance in early successional stages in the Cascade Range (Kienholz 1929; Isaac 1940; Yerkes 1960). However, in the Coast Ranges of Oregon, residual species, especially *Polystichum munitum*, often constitute an important component of the seral vegetation following logging. In addition, both shrub and total plant cover tend to be substantially greater on Coast Ranges cutting units than in the Cascades (Morris 1958). Typical shrub species near the

Figure 48. — A stage of shrub dominance typically follows herbaceous stage in *Tsuga heterophylla* Zone secondary successions; *Rhododendron macrophyllum*, residual from the original forest stand, dominates this 10-year-old clearcut (Santiam River drainage, Willamette National Forest, Oregon).

coast include *Rubus spectabilis*, *Rubus parviflorus*, and *Gaultheria shallon*.

The vegetation in early stages of succession following logging and burning is characteristically very heterogeneous. Much of this variability is attributable to site differences caused by a wide range of types of logging disturbance and degrees of burning severity (Dyrness 1965). The effects of burning in control of species composition are perhaps the most notable. For example, annual invading herbaceous species, such as *Senecio sylvaticus* and *Epilobium paniculatum*, show a marked preference for burned areas; whereas residual species such as *Polystichum munitum* and *Trientalis latifolia* occur more frequently on unburned sites. Of the shrubs, *Ceanothus* spp. are often almost entirely restricted to burned areas, and residual species (e.g., *Rhododendron macrophyllum* and *Vaccinium parvifolium*) generally are much more common on unburned sites (Morris 1958; Steen 1966).

Later successional stages in the *Tsuga heterophylla* Zone have received little study. However, Bailey and Poulton (1968) attempted a classification of the vegetation of a portion of the Tillamook Burn in the Coast Ranges of Oregon approximately 20 years after its most recent fire. They found the seral vegetation to be classifiable into six associes which showed consistent relationships to environmental factors. These associes ranged from *Vaccinium parvifolium/Gaultheria shallon* on relatively xeric sites to *Alnus rubra/Polystichum munitum* on mesic sites. They also described an *Acer circinatum/Polystichum munitum* associes which closely resembles a similar community widely distributed in the Coast Ranges under 100-year-old stands of *Pseudotsuga menziesii*.

The relationships between early stages of secondary succession and plant communities, present in the original *Pseudotsuga menziesii-Tsuga heterophylla* stands, have been studied on Vancouver Island by Mueller-Dombois (1965) and in the southern Oregon Coast Ranges by Bailey (1966). Both workers found that in these coastal areas the characteristic forest plants were present in sufficient quantities after logging and burning to permit successful identification of the preexisting communities. Mueller-Dombois concluded that the cutover vegetation is denser than that found under the original stand due to spreading forest weeds, semitolerant of shade, and invading shade-intolerant weeds. Both weed groups compete for the same vacant spaces, but in general, the intolerant weeds appear to be more successful in burned areas and the semitolerant forest weeds in unburned localities.

The composition and density of the seral forest stands is dependent on the type of disturbance, available seed source, and environmental conditions. A very common occurrence is the development of dense, nearly pure, essentially even-aged stands of *Pseudotsuga menziesii* (fig. 49). This tendency is encouraged by the extensive planting and seeding of this species after logging or wildfires. These stands are often dense enough to eliminate most of the understory vegetation (fig. 50). Reestablishment of the characteristic understory species and invasion of western hemlock then takes place as mortality begins to open up the stand at 100 to 150 years of age. On the other hand, stands of *Pseudotsuga* may be relatively open, resulting in persistent understories dominated by *Gaultheria shallon* or *Acer circinatum*. Other common types of young stands in the zone are (1) those dominated by *Alnus rubra*, particularly on *Polystichum munitum*-characterized habitats (Bailey and Poulton 1968), and (2) stands in which *Tsuga heterophylla* or *Thuja plicata* are major components right from the beginning of secondary forest development. The latter two situations are most commonly found in wetter parts of the *Tsuga heterophylla* Zone; i.e., the northern Washington Cascade Range, the west side of the Olympic Mountains, and in the Coast Ranges.

Truly climax forests are rare, but examples of old-growth forests which have been undisturbed for 400 to 600 years are relatively common. From these, we can draw some conclusion about the potential climax species. The eventual replacement of *Pseudotsuga* by *Tsuga heterophylla* in the absence of disturbance has been described by many authors (e.g., by Munger 1940, Hansen 1947, Cooper 1957, and Barrett 1962, in general terms, and by Bailey 1966, Fonda 1967, and Orloci 1965 for specific areas). As mentioned, *Tsuga heterophylla* may appear with the *Pseudotsuga* and a mixed stand develop. On other sites, significant *Tsuga* invasion may not occur for 50 or 100 years after disturbance. The point is that on most sites in the zone, *Tsuga heterophylla* is able to reproduce itself beneath the forest canopy and the relatively intolerant *Pseudotsuga* is not (fig. 51). Numerous examples can be found of mixed old-growth *Pseudotsuga-Tsuga* forest in which abundant seedlings, saplings, and poles of *Tsuga heterophylla* are present and those of *Pseudotsuga* are completely lacking.

However, there is some variation within the zone regarding the climax tree species. On environmentally median sites, *Tsuga heterophylla* appears to be essentially the sole climax species. On very dry sites, *Tsuga heterophylla* is absent and, consequently, *Pseudo-*

Figure 49. — Dense, nearly pure, essentially even-aged *Pseudotsuga menziesii* stands typically develop on cutover areas in western Washington and northwestern Oregon by natural seeding or planting.

Figure 50. — Young conifer stands in the *Tsuga heterophylla* Zone are often dense enough to completely eliminate most of the understory; dense 66-year-old *Pseudotsuga menziesii* stand near Cottage Grove, Oregon.

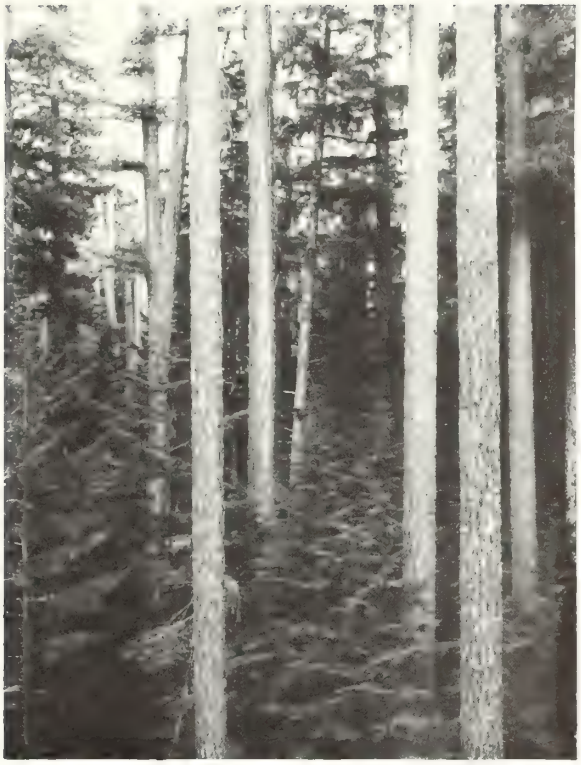


Figure 51. — The shade-tolerant, climax *Tsuga heterophylla* is capable of reproducing under a forest canopy, but the intolerant *Pseudotsuga menziesii* is not; *Tsuga* saplings developing under a *Pseudotsuga* overstory (Santiam River drainage, Willamette National Forest, Oregon).

tsuga menziesii attains a climax role. On the wet to very wet sites, *Thuja plicata* will certainly be a part of any climax forest; size-class analyses do not support climax status for this species on modal or dry sites, however, even though many ecologists have hypothesized a *Tsuga-Thuja* climax for most of the region. The tendency for *Thuja plicata* to be a part of the mixed stands, successionally intermediate between the pioneer *Pseudotsuga* forests and the climax *Tsuga heterophylla* forests, has perhaps misled some ecologists in interpreting its successional role.

Special Types

Puget Sound area. — Here, large areas differ from the surrounding *Tsuga heterophylla* Zone in community types. Prairie, oak woodland, and pine forest are encountered, for example. Climate and soil are both major factors in these differences. The area lies in the rain shadow of the Olympic Mountains. Precipitation is typically between 800 and 900 millimeters in the Puget lowlands, although it drops as low as 460 millimeters on the northeastern side of the Olympic Peninsula and in the San Juan Islands (U. S. Weather Bureau 1960b). And, as pointed out earlier, a continental ice sheet covered the Puget Trough during the Pleistocene epoch (Vashon glaciation). Consequently, most soils are developed in glacial drift and outwash. Such soils are often coarse textured, poor in nutrients, and excessively drained.

Although plant communities around Puget Sound are similar to others in the *Tsuga heterophylla* Zone, there are many notable features which are not common elsewhere: (1) stands with *Pinus contorta*, *Pinus monticola*, and even *Pinus ponderosa* as major constituents along with *Pseudotsuga menziesii*, and with *Gaultheria shallon* as an extremely common understory species; (2) *Quercus garryana* groves — many being actively invaded by *Pseudotsuga menziesii;* (3) extensive prairies often being invaded by *Pseudotsuga menziesii* and associated with groves of *Quercus;* (4) abundant poorly drained sites with swamp or bog communities; and (5) occurrence of species rarely or never found elsewhere in western Washington or northwestern Oregon, e.g., *Juniperus scopulorum*, *Populus tremuloides*, *Pinus ponderosa*, and *Betula papyrifera.* None of these communities or community mosaics, excepting the bogs (Rigg 1917, 1919, 1922a, 1922c, 1958; Fitzgerald 1966), have been studied in detail, although generalized accounts of one or more may be found in Barrett (1962), Hansen (1947), and Rigg (1913).

Many of these features are found on the Tacoma Prairies (Hansen 1947) near Olympia, Washington. *Quercus garryana*, *Pseudotsuga menziesii*, some *Pinus contorta*, and occasional *Pinus ponderosa* are associated with extensive open areas or prairies. The development of prairie (grassland) soil profiles in some openings indicates they have been free of forest for many years; possibly they were periodically burned by Indians to aid in hunting and to maintain the lileaceous *Camassia* roots,

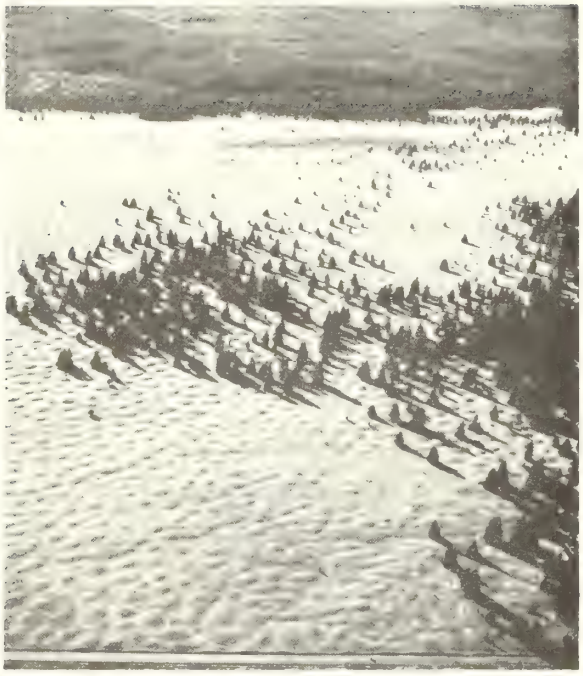


Figure 52. — Mima Prairie near Olympia, Washington, showing (1) distribution of the mima mounds, which average 12 meters in diameter and 2 meters in height, and (2) invasion of a prairie area by *Pseudotsuga menziesii* (*photo courtesy V. B. Scheffer*).

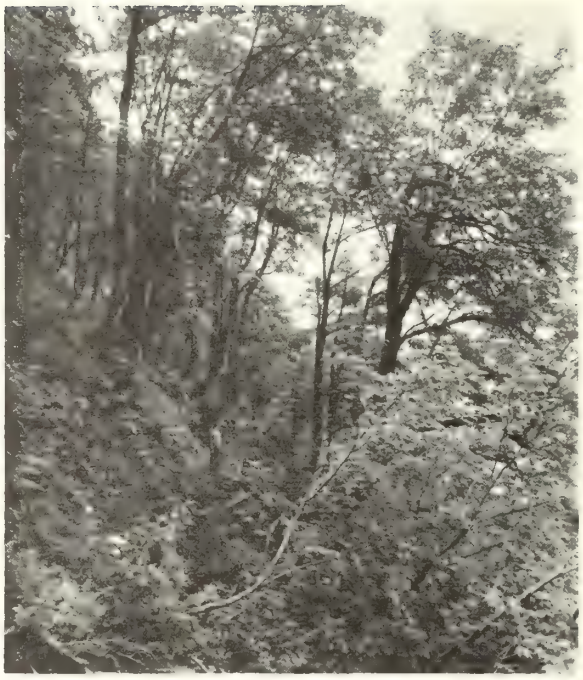


Figure 53. — Talus communities dominated by *Acer macrophyllum* (background) or *Acer circinatum* (foreground) are widespread in the *Tsuga heterophylla* Zone (Lake Twentytwo Research Natural Area, Mount Baker National Forest, Washington).

which they used for food. Hansen (1947) has noted that *Tsuga heterophylla* pollen was never as abundant in local pollen profiles as in other parts of the Puget Trough. *Pseudotsuga* is now rapidly invading the prairies as well as *Quercus* groves (fig. 52).

"Mima mounds" are found on some of these prairies (fig. 52). These mounds range from swellings on the prairie surface to a maximum of about 2.1 meters in height and average about 12.2 meters in diameter. Several different theories of origin have been proposed, two of which are seriously considered. Dalquest and Scheffer (1942) attributed them to gopher activity *(Thomomys talpoides).* Newcomb (1952) related them to the glacial climate by proposing the mounds were due to thrusting action of ground ice wedges.

Eventually, the Puget lowlands may be recognized as a separate vegetative zone similar to the Coastal Douglas-fir Zone found in British Columbia (Krajina 1965). Its close relations with this zone are obvious. Many of the Puget lowland communities also appear related to those found in the Willamette Valley; possibly some ecologists would group them together. However, both coastal British Columbia and the Puget Sound areas were glaciated and do involve large bodies of ocean water which significantly affect the local climate. Neither of these circumstances applies to the Willamette and other interior valleys of western Oregon.

Talus communities. — Nonforested talus or scree slopes occur in many parts of the *Tsuga heterophylla* Zone. Very often the communities on these sites are dominated by the shrub *Acer circinatum*. These should probably be described as a series of communities because of the great variety in stand composition and structure, depending on substrate (size, arrangement, and chemistry of rocks, moisture conditions), elevation, exposure, etc. Some typical associates of *Acer circinatum* on more xeric talus include *Cryptogramma acrostichoides, Festuca occidentalis, Holodiscus discolor, Symphoricarpos mollis, Corylus cornuta* var. *californica, Cheilanthes gracillima,*

Figure 54. — *Chamaecyparis lawsoniana* is found in the southern part of the *Tsuga heterophylla* Zone and attains optimal development there; note the dense understory of evergreen shrubs (Siskiyou National Forest, Oregon).

Selaginella wallacei, *Xerophyllum tenax*, *Synthyris reniformis*, *Rhacomitrium canescens* var. *ericoides*, *Aira caryophyllea*, and *Ceanothus sanguineus*. *Acer circinatum*-dominated talus communities may be found well into the *Abies amabilis* Zone and be intergraded with the *Alnus sinuata* communities described later in this paper.

Talus communities dominated by *Acer macrophyllum* occur in the Oregon Coast

Figure 55. — Old-growth *Chamaecyparis lawsoniana* are quite fire resistant, and vigorous specimens frequently have deep basal fire scars (Coquille River Falls Research Natural Area, Siskiyou National Forest, Oregon).

Ranges (Bailey and Poulton 1968). Similar communities have been noted in northern Washington (fig. 53).

Port-Orford-cedar variant — Near its southern edge in the Oregon Coast Ranges, *Chamaecyparis lawsoniana* is added to *Tsuga heterophylla* Zone forests. In these forests, *Chamaecyparis* is associated with species such as *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Abies grandis*, *Thuja plicata* (only on wetter sites), *Lithocarpus densiflorus*, *Rhododendron macrophyllum*, *Arbutus menziesii*, and *Pinus lambertiana* (fig. 54). It appears to have the same ecological role as *Pseudotsuga menziesii*, a long-lived but seral dominant. Old-growth specimens of *Chamaecyparis lawsoniana* develop thick bark and are quite resistant to fire. Old but vigorous specimens frequently have numerous fire scars (fig. 55). Structural analyses of old-growth stands indicate it is not capable of reproducing under closed forest conditions and is replaced by more tolerant associates — *Abies grandis* and *Tsuga heterophylla*.[6]

Chamaecyparis lawsoniana is considered in this discussion of the *Tsuga heterophylla* Zone because it attains optimum development there. In fact, it grows in several different zones and on a wide variety of sites in south-

[6] Data on file at Forestry Sciences Laboratory, Pacific Northwest Forest & Range Exp. Sta., Forest Serv., U. S. Dep. Agr., Corvallis, Oregon.

Figure 56. — Mixed stands are typical of the *Abies amabilis* Zone; overstory dominants in this stand are *Abies procera*, *Pseudotsuga menziesii*, and *Tsuga heterophylla* (background), but poles (foreground) and reproduction are the climax *Abies amabilis* (Wildcat Mountain Research Natural Area, Willamette National Forest, Oregon).

western Oregon — from sand dunes along the coastal strip to over 1,500 meters in the Siskiyou Mountains and down into the interior valleys; from swampy sites to dry, rocky ridges; and even on serpentine soils (Whittaker 1960; Fowells 1965). Indeed, it is difficult to understand why the natural range of the species is so restricted geographically. *Chamaecyparis lawsoniana* is seriously threatened by a killing root disease, *Phytophthora lateralis*, which was recently introduced into its natural range. This disease has already decimated *Chamaecyparis lawsoniana* in the coastal region and could possibly eliminate it from most of its natural range.

"ABIES AMABILIS" ZONE

The *Abies amabilis* Zone lies between the temperate mesophytic *Tsuga heterophylla* Zone of the lowlands and the subalpine *Tsuga mertensiana* Zone. It occurs on the western slopes of the Cascade Range from British Columbia south to about 44° north latitude, generally at elevations from 1,000 to 1,500 meters in Oregon and 600 to 1,300 meters in northern Washington. The *Abies amabilis* Zone is also conspicuous in the Olympic Mountains, except in the rain shadow on the northeastern slopes of the peninsula (Fonda 1967). Where local conditions are favorable, comparable communities are found (1) on eastern slopes of Washington's Cascade Range, (2) south to 43° north latitude in Oregon's Western Cascades Province, and (3) on wet, cool sites (streamsides and benches) in the *Tsuga heterophylla* Zone. Our *Abies amabilis* Zone is analogous to the Wet Subzone, Coastal Western Hemlock Zone of Krajina (1965); it includes all of the poorly defined Canadian Life Zone (Barrett 1962).

Environmental Features

The *Abies amabilis* Zone is wetter and cooler than the adjacent *Tsuga heterophylla* Zone and receives considerably more precipitation in the form of snow (table 9), much of which accumulates in winter snowpacks as deep as 1 to 3 meters. The complex of soil-forming processes leads toward podzolization. This trend is less pronounced in the south where Brown Podzolic soils are the rule, and most pronounced in the north where true Podzols are typical. Organic matter accumulations are of a mor or duff-mull type. These generally average only 5 to 10 centimeters thick, except in northern Washington where accumulations up to 30 centimeters or more in thickness are encountered along with well-developed bleicherde (A2) and ortstein (B2ir) mineral horizons.

Forest Composition

Forest composition in the *Abies amabilis* Zone varies widely, depending upon stand age, history, and locale (Franklin 1965a, b). Typical tree species are *Abies amabilis*, *Tsuga heterophylla*, *Abies procera*, *Pseudotsuga menziesii*, *Thuja plicata*, and *Pinus monticola* (fig. 56). Around Mount Adams and in Oregon, *Abies lasiocarpa*, *Abies grandis*, *Picea engelmannii*, *Pinus contorta*, and *Larix occidentalis* may also occur in the zone. At its upper margin, *Tsuga mertensiana* and *Chamaecyparis nootkatensis* appear. Understories

Table 9. — Climatic data from representative weather stations within the *Abies amabilis* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Snoqualmie Pass, Wash.	991	47°25′	121°25′	5.5	−3.2	−6.6	14.4	21.1	2,656	227	982
Spirit Lake, Wash.	1,063	46°16′	122°09′	5.6	−2.0	−4.4	14.9	22.3	2,253	140	718
Government Camp, Oreg.	1,280	45°18′	121°45′	5.6	−1.7	−4.9	14.0	20.8	2,190	190	792

Source: U. S. Weather Bureau (1956, 1965a).

are usually dominated by ericaceous genera, such as *Vaccinium*, *Menziesia*, *Gaultheria*, *Chimaphila*, *Rhododendron*, and *Pyrola*. *Cornus canadensis*, *Clintonia uniflora*, *Rubus lasiococcus*, *R. pedatus*, *Linnaea borealis*, *Xerophyllum tenax*, and *Viola sempervirens* are also common species. *Rhytidiopsis robusta* is the most constant and conspicuous bryophyte.

Forested communities vary markedly in composition from very dry to very moist sites. In southern Washington (Franklin 1966) the *Abies amabilis/Vaccinium alaskaense* association is the zonal climax. It is characterized by well-developed shrub, herb, and moss layers (fig. 57). *Vaccinium alaskaense*, *V. ovalifolium*, *Cornus canadensis*, *Clintonia uniflora*, *Linnaea borealis*, and *Rhytidiopsis robusta* typify these modal communities. On drier sites are associations with depauperate understories dominated by low shrubs such as *Berberis nervosa* and *Gaultheria shallon* or, on lithosolic sites, by the coarse liliaceous *Xerophyllum tenax*. More mesic sites have communities with herb-rich understories dominated by species such as *Tiarella unifoliata*, *Streptopus curvipes*, *Achlys triphylla*, *Dryopteris linnaeana*, *Vancouveria hexandra*, *Oxalis oregana*, *Struthiopteris spicant* and *Smilacina sessilifolia* (figs. 58 and 59). Communities on the wettest forested sites have dense, rich understories typified by *Athyrium filix-femina* and *Oplopanax horridum*.

Figure 57. — Understory in an *Abies amabilis/Vaccinium alaskaense* community, the zonal climax in the southern Washington Cascade Range; *Vaccinium alaskaense*, *Xerophyllum tenax*, *Cornus canadensis*, *Clintonia uniflora*, and *Rhytidiopsis robusta* are notable species (Wind River Research Natural Area, Gifford Pinchot National Forest, Washington).

Figure 58. — *Abies procera* attains maximum development on mesic sites in the *Abies amabilis* Zone; these sites are characterized by herb-rich understories (near Mount St. Helens, Gifford Pinchot National Forest, Washington).

There is considerable geographic variation in *Abies amabilis* communities. Thornburgh (1969) found it more useful to consider *Abies amabilis* Zone communities near Mount Rainier as a continuum. In the Olympic Mountains (Fonda 1967) and Northern Cascade Range, herb-rich communities characterized by species such as *Oxalis oregana* or *Struthiopteris spicant* are more common than in the southern Washington Cascades. In Oregon, changes include: (1) reduced importance of *Vaccinium alaskaense-Cornus canadensis* communities, (2) increased importance of communities with herbaceous and *Vaccinium membranaceum-Xerophyllum tenax* understories, and (3) addition of *Rhododendron macrophyllum* as an understory dominant on some sites. A community dominated by *Picea engelmannii* and *Abies amabilis* with a rich herbaceous understory is found on wet, frosty habitats in Oregon's western Cascade Range.

Successional Patterns

The major climax species throughout the zone is *Abies amabilis* (Thornburgh 1969; Fonda 1967; Franklin 1966); size and age class analyses of many stands illustrate this clearly (fig. 60). A typical successional sequence begins with invasion of the site by *Pseudotsuga menziesii* or *Abies procera*, or both. Western hemlock may be established simultaneously or develop later under a forest canopy, or both. In any case, *Pseudotsuga* and *Abies procera* fail to reproduce. The heavy-seeded, fire-sensitive *Abies amabilis* is usually last to invade the site (Schmidt 1957), coming in under the mixed canopy of *Pseudotsuga menziesii*, *Abies procera*, and *Tsuga heterophylla*; if seed sources are available, *Abies amabilis* can also function as a pioneer species, however.

Four hundred to 500 years after disturbance, a typical mixed stand includes scattered, large (100- to 150-cm. d.b.h.) *Pseudotsuga menziesii*, more abundant but somewhat smaller (70- to 100-cm. d.b.h.) *Tsuga heterophylla*, and abundant seedlings, saplings, and poles of *Abies amabilis*. Many stands with this or a similar structure are encountered in the Cascade Range.

Replacement of the shade-tolerant *Tsuga heterophylla* by *Abies amabilis* on most sites is probably a consequence of mechanical factors (Thornburgh 1969). Fragile *Tsuga* seedlings are unable to survive winter accumulations of litter and snow characteristic of forest floors in the zone, whereas those of *Abies amabilis* are (Thornburgh 1969). Surviving *Tsuga heterophylla* reproduction is invariably confined to down logs and mounds of rotten wood. *Tsuga heterophylla* seedlings do conduct photosynthesis more efficiently at low light intensities, and reportedly they grow faster than those of *Abies amabilis* (Thornburgh 1969). However, their successional relationship reverses itself at the lower edge of the zone.

Stand structure analyses indicate *Tsuga heterophylla* is a minor climax species along with *Abies amabilis*, especially at lower elevations within the zone. Climax species on wet sites are not easily predicted since seedlings and saplings of all species are relatively scarce. It does appear that both *Tsuga heterophylla* and *Thuja plicata* are at least minor climax species.

Early stages in forest succession (from disturbance through development of a closed forest canopy) have not been studied in de-

Figure 59. — Lush herbaceous understories typify forest understories on moist sites in the *Abies amabilis* Zone; *Achlys triphylla*, *Vancouveria hexandra*, *Dryopteris linnaeana*, and *Streptopus curvipes* on *Abies amabilis/Streptopus* habitat type (Gifford Pinchot National Forest, Washington).

Figure 60. — *Abies amabilis* is the major climax species in this zone dominating the reproduction in old-growth stands; *Abies amabilis* saplings in an *Abies procera* stand (Wildcat Mountain Research Natural Area, Willamette National Forest, Oregon).

Figure 61. — *Alnus sinuata* communities are on sites subject to heavy snow accumulations and snow creep or avalanching; hence, the 3- to 5-meter-tall *Alnus* have strongly bowed stems (H. J. Andrews Experimental Forest, Oregon).

Figure 62. — *Alnus sinuata* communities are permanently maintained on some sites by recurrent snow avalanches (Mount Rainier National Park, Washington).

tail. However, major dominants during the preforest stage of succession are generally species present in the forest stands before disturbance. Some examples are all the *Vaccinium* spp., *Xerophyllum tenax*, and *Sorbus* spp. *Pteridium aquilinum* is often a major invader not present before disturbance. An exception to these generalizations is on wet sites where disturbance may produce dense shrub communities of *Sambucus*, *Rubus spectabilis*, and *Ribes* spp.

Special Types

Alnus sinuata **communities.** — *Alnus sinuata* characterizes a community type found most often in this zone. These shrub communities occupy sites subject to deep winter snow accumulations and extensive snow creep; they often suffer recurrent snow avalanches as well. Consequently, *Alnus sinuata* individuals, 3 to 5 meters tall, have strongly bowed stems (fig. 61). In the Washington Cascade Range, repeated avalanching is at least partially responsible for creation and maintenance of these communities (fig. 62). In Oregon, *Alnus sinuata* communities appear on sites that are not avalanche tracks but do have heavy snow accumulations and abundant seepage water. High water tables have been ascribed to a nearly impervious subsoil in some areas,[7] but in others there appears to be no difference in substrate between forest and shrub communities (Daubenmire and Daubenmire 1968; Aller 1956). *Alnus sinuata* communities are to all appearances a stable community type or are only very slowly encroached upon by forest vegetation. The only conifer capable of surviving and reproducing

[7] Unpublished soil survey data from the H. J. Andrews Experimental Forest on file with Forestry Sciences Laboratory, Pacific Northwest Forest & Range Exp. Sta., Forest Serv., U. S. Dep. Agr., Corvallis, Oregon.

on sites with recurrent avalanches is *Chamaecyparis nootkatensis*. Since the sites occupied by *Alnus sinuata* communities are normally very wet, the understory is typically rich in dicotyledonous herbs, such as *Montia* spp., ferns, and Carices and usually includes *Oplopanax horridum*. Similar communities occur in higher forested zones on the east slopes of the Cascade Range, in the northern Rocky Mountains (Daubenmire and Daubenmire 1968), and in the Blue Mountains where *Alnus tenuifolia* dominates.[8]

Meadow communities. — There are many types of mountain meadow and other nonforested communities associated with the *Abies amabilis* Zone. A mesic meadow type, dominated by *Pteridium aquilinum* and *Rubus parviflorus*, is extremely widespread and is often contiguous with *Alnus sinuata* communities and may intergrade with subalpine meadow types at higher elevations.[9] Hickman (1968) categorized and listed constituent species for the different vegetation types found in forest openings along the ridges and peaks of Oregon's Western Cascades province; the majority of these are associated with the *Abies amabilis* Zone. Included in Hickman's lists are three different meadow types, and seep, talus, and outcrop communities.

"TSUGA MERTENSIANA" ZONE

The *Tsuga mertensiana* Zone is the highest forested zone along the western slopes and crest of the Cascade Range and in the Olympic and Klamath Mountains. Elevational limits of the *Tsuga mertensiana* Zone are generally between 1,300 and 1,700 meters in northern Washington and 1,700 and 2,000 meters in the southern Oregon Cascades. The zone extends varying distances east of the Cascade crest until it is gradually replaced by the *Abies lasiocarpa* Zone more typical of interior subalpine environments. A similar replacement of *Tsuga mertensiana* forests by those of *Abies lasiocarpa* occurs in the rain shadow portion of the Olympic Mountains (Fonda 1967). *Tsuga mertensiana*-dominated forests reappear in portions of the northern Rocky Mountains in association with those of *Abies lasiocarpa* and *Picea engelmannii* (Daubenmire 1952; Daubenmire and Daubenmire 1968; Habeck 1967).

The *Tsuga mertensiana* Zone can be divided into major subzones — a lower subzone of closed forest and an upper parkland subzone. In the lower subzone, there is essentially continuous forest cover of *Tsuga mertensiana* and its associates. The upper subzone is a mosaic of forest patches and tree groups interspersed with shrubby or herbaceous subalpine communities. In this section, we will be concerned only with the lower subzone; the subalpine meadow-forest mosaic will be considered during the discussion of timberline and alpine regions.

As defined here, the *Tsuga mertensiana* Zone is comparable to the Mountain Hemlock Zone of Krajina (1965). It also includes most of the Hudsonian Life Zone (Barrett 1962) and, perhaps, the upper part of the Canadian Life Zone as well.

Environmental Features

The *Tsuga mertensiana* Zone is wet and the coolest of the forested zones in western Oregon and Washington (table 10). Annual precipitation ranges from about 1,600 to 2,800 millimeters. This includes 400 to 1,400 centimeters of snowfall which accumulates in snowpacks up to 7.5 meters deep.

Soils within the zone are podzolic, although the degree of podzolization varies greatly. In the north, Podzols and Gley Podzolic soils are common, with well-developed mor humus layers. In central and southern Oregon, true Podzols are rare and weakly developed Brown Podzolic soils with a relatively thin, but densely matted, mor humus layer are the rule.

Forest Composition

Forest composition within the zone varies considerably with locale (table 11). Relatively few species are found as dominants — *Tsuga mertensiana* in old-growth forests throughout

[8] Personal communication, Dr. F. C. Hall.

[9] Personal communication, Mr. G. W. Douglas.

Table 10. – Climatic data from representative weather stations within the *Tsuga mertensiana* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Mount Baker Lodge, Wash.	1,362	48°52′	121°40′	4.5	−2.6	−5.7	12.1	17.5	2,821	313	1,398
Paradise Ranger Station, Wash.	1,821	46°47′	121°44′	3.4	−3.4	−7.0	11.6	17.4	2,635	226	1,362
Crater Lake National Park Headquarters, Oreg.	2,124	42°54′	122°08′	3.8	−3.7	−8.4	13.4	21.9	1,643	99	1,324

Source: U. S. Weather Bureau (1956, 1965a, 1965b).

Table 11. — Relative importance of tree species in the closed-forest subzone of the *Tsuga mertensiana* Zone

Species	Washington		Oregon	
	Western Cascades	Eastern Cascades	Northern Cascades	Southern Cascades
Abies amabilis	[1] M	m	M	—
Abies lasiocarpa	m	M	M	—
Abies magnifica var. *shastensis*	—	—	—	M
Abies procera	m	—	m	—
Chamaecyparis nootkatensis	M	m	m	—
Picea engelmannii	—	m	m	m
Pinus albicaulis	—	m	m	m
Pinus contorta	m	M	M	M
Pinus monticola	m	m	m	m
Pseudotsuga menziesii	m	m	m	—
Thuja plicata	m	—	—	—
Tsuga heterophylla	m	m	m	—
Tsuga mertensiana	M	M	M	M

[1] M indicates a species is a major constituent of either seral or climax forests or both; m indicates a species is a minor component.

Figure 63. — Pure, old-growth stands of *Tsuga mertensiana* are common throughout the *Tsuga mertensiana* Zone; note the clumping tendency of the trees in this stand near timberline (Gifford Pinchot National Forest, Washington).

the zone (fig. 63), and *Abies lasiocarpa* or *Pinus contorta*, or both, in seral stands in drier portions of the zone. *Abies amabilis* is conspicuous in the zone in Washington and northern Oregon, but it drops out completely in the southern Oregon High Cascades. There are a wide variety of understory species of which many are Ericaceae, Rosaceae, and Compositae.

The spectrum of communities found within the *Tsuga mertensiana* Zone varies locally with gradients in temperature, moisture, and accumulation and duration of snow, as well as geographically. In southern Washington the *Tsuga mertensiana-Abies amabilis/Vaccinium membranaceum* community is typical of modal sites. It has a depauperate understory composed of *Vaccinium membranaceum*, *Xerophyllum tenax*, *Pyrola secunda*, *Rubus lasiococcus*, and perhaps a few additional species. A variant of this community, in which the understory is completely dominated by a dense cover of *Xerophyllum tenax*, is common in the southern Washington and northern Oregon Cascade Range (fig. 64).

On wetter, cooler habitats, e.g., north slopes and along drainages, communities have dense shrub understories 1 to 1-1/2 meters in height. The most extreme example in southern Washington is a *Chamaecyparis nootkatensis/Rhododendron albiflorum*/Gley Podzol association (Franklin 1966). A tangle of *Vaccinium ovalifolium*, *V. membranaceum*, *Rhododendron albiflorum*, *Menziesia ferruginea*, and *Sorbus* spp. is characteristic of this shrub layer. Typical herbs include *Rubus pedatus*, *R. lasiococcus*, *Valeriana sitchensis*, *Viola sempervirens*, *Listera caurina*, and *Erythronium montanum*.

In southern Oregon, the extensive *Tsuga mertensiana* communities found along the crest of the Cascade Range are much simpler structurally and floristically. The sparse understories are usually dominated by *Vaccinium membranaceum* or *V. scoparium* along with minor amounts of other species such as *Chimaphila umbellata* and *Arctostaphylos nevadensis*.

Successional Patterns

Large acreages of the *Tsuga mertensiana* Zone have been burned over during the last 150 years in southern Washington and Oregon. Consequently, seral communities are often conspicuous. Early stages in succession have not been studied, but they often involve domination of the site by fire-resistant species conspicuous in the understory — *Vaccinium membranaceum* and *Xerophyllum tenax*, for example.

Forest development on burned areas is often very slow, as would be expected in the severe environment of this zone. In some cases, semipermanent communities of *Vaccinium* spp., *Xerophyllum*, *Sorbus* spp., and *Spiraea* have been created by repeated burning (fig. 65). Indians used this method to perpetuate fields of *Vaccinium membranaceum* from which they collected berries for food.

Successional sequences of tree species vary geographically. On moist sites, *Tsuga mertensiana* and *Abies amabilis* can function as pioneer species. On dry sites, and particularly in Oregon's High Cascades province, seral forests of *Pinus contorta* or *Abies lasiocarpa* are often the first to develop (fig. 66). These are gradually replaced by *Tsuga mertensiana* and, except in southern Oregon, by *Abies amabilis*.

In Washington and northern Oregon, *Abies amabilis* appears to be the major climax species in closed-forest portions of the *Tsuga mertensiana* Zone (Franklin 1966; Thornburgh 1969). Although nearly all old-growth stands do contain mature *Tsuga mertensiana*, reproduction is often nearly absent; a full range of *Abies amabilis* size classes is usually present. *Tsuga mertensiana* and *Chamaecyparis nootkatensis* may be minor climax species on some habitats. In southern Oregon, more tolerant arborescent associates are absent from *Tsuga mertensiana* stands and *Tsuga* is the climax species. Apparently, regeneration develops after the old-growth stands begin to break up, since significant *Tsuga mertensiana* regeneration is not common under closed-forest canopies.

Southwestern Oregon

Southwestern Oregon is an extremely interesting and complex region environmentally, floristically, and synecologically. Climate ranges from cool and moist in the coastal regions to hot and dry in the interior valleys, which are the driest locales west of the Cascade Range. The geology and, consequently, soils are extremely varied. Floristically the region combines elements of the Californian, north coast, and eastern Oregon floras, with a large number of species indigenous only to the Klamath Mountains region (Whittaker

Figure 64. — Communities with understories dominated by *Xerophyllum tenax* and *Vaccinium membranaceum* are very widespread on poorer sites in the *Tsuga mertensiana* Zone; a *Tsuga mertensiana-Abies amabilis/Xerophyllum tenax* community on a ridgetop with shallow soil (Wildcat Mountain Research Natural Area, Willamette National Forest, Oregon).

Figure 65. — Fields of *Vaccinium membranaceum* and other shrubs have been created and maintained by repeated burning in the *Tsuga mertensiana* and *Abies amabilis* Zones (near Mount Adams, Washington; *photo courtesy Gifford Pinchot National Forest*).

Figure 66. — *Pinus contorta* is a major pioneer species in High Cascades portions of the *Tsuga mertensiana* Zone; here, *Tsuga mertensiana* is developing in a stand of dead and dying *Pinus contorta* (near Olallie Butte, Mount Hood National Forest, Oregon).

1960, 1961). This environmental and floristic diversity combines with a long history of prehistoric and historic disturbances, primarily by fire, to produce an extremely varied array of communities.

This section deals with portions of southwestern Oregon lying outside the *Tsuga heterophylla* and *Picea sitchensis* Zones. It includes the main body of the Siskiyou Mountains,[10] interior valleys, and western slopes of the Cascade Range. Most of the region is potentially occupied by forest communities of some kind.

[10] The Siskiyou Mountains are the northernmost range in the Klamath Mountains group (Irwin 1966). Since this is the only range in this group encountered in Oregon, we will use the term "Siskiyou Mountains."

The major southwestern Oregon tree species can be arrayed in relation to tolerance of moisture stress:

Species	Tolerance
Quercus garryana	High
Quercus kelloggii	↓
Pinus ponderosa	↓
Arbutus menziesii	↓
Libocedrus decurrens	↓
Pseudotsuga menziesii	↓
Pinus lambertiana	↓
Pinus monticola	↓
Abies concolor	↓
Chamaecyparis lawsoniana	↓
Abies magnifica var. *shastensis*	↓
Tsuga mertensiana	↓
Tsuga heterophylla	Very low

We might expect a systematic sequence of zones along the moisture and temperature gradients (which are broadly correlated with elevation) based on this array and the relative shade tolerance of the species:

Species	Tolerance
Tsuga heterophylla	High
Abies concolor	↓
Tsuga mertensiana	↓
Chamaecyparis lawsoniana	↓
Pseudotsuga menziesii, *Libocedrus decurrens*	↓
Abies magnifica var. *shastensis*	↓
Pinus lambertiana	↓
Pinus monticola	↓
Pinus ponderosa	↓
Arbutus menziesii	↓
Quercus garryana, *Quercus kelloggii*	Low

In fact, history and environmental complexity often make it impossible to distinguish zones, particularly in the heavily disturbed valley regions. Furthermore, very few data on plant communities are available for the interior valleys and western slopes of the Cascade Range. Therefore, we have taken a more typological approach. The "zonal" outline is as follows

(no climax implication is intended in naming the first three zones):

Interior Valley Zone (*Pinus-Quercus-Pseudotsuga*)
Mixed-Evergreen Zone (*Pseudotsuga*/sclerophyll)
Mixed-Conifer Zone (*Pseudotsuga-Pinus-Libocedrus-Abies*)
Abies concolor Zone
Abies magnifica shastensis Zone

The *Abies magnifica shastensis* Zone is bounded at its upper limits by the *Tsuga mertensiana* Zone (discussed earlier) wherever elevations are sufficiently great (Siskiyou Mountains and Cascade Range).

The arrangement of these zones in the Cascade Range and eastern and western Siskiyou Mountains is illustrated in figure 67. The only major difference is the replacement of the Mixed-Conifer Zone by a Mixed-Evergreen Zone in the western Siskiyou Mountains. It will be obvious that most of the major formations found in southwestern Oregon are actually the northern extensions of formations which are considered typical of the California Coast Ranges and Sierra Nevada.

Fire has played an extremely important role in southwestern Oregon. Fire danger can reach very high levels during the long, hot, dry summers. Fires, both naturally caused and Indian-set, were common prior to the arrival of the white man. Early settlers were responsible for additional burning, but formal fire control activities have been in effect since the early 1900's. As will be seen, many of the communities are created and perpetuated by fires; e.g., some sclerophyllous shrub (chaparral) types and *Pinus attenuata* forests. Fire and fire control activities are having a profound influence on the shape of the future landscape.

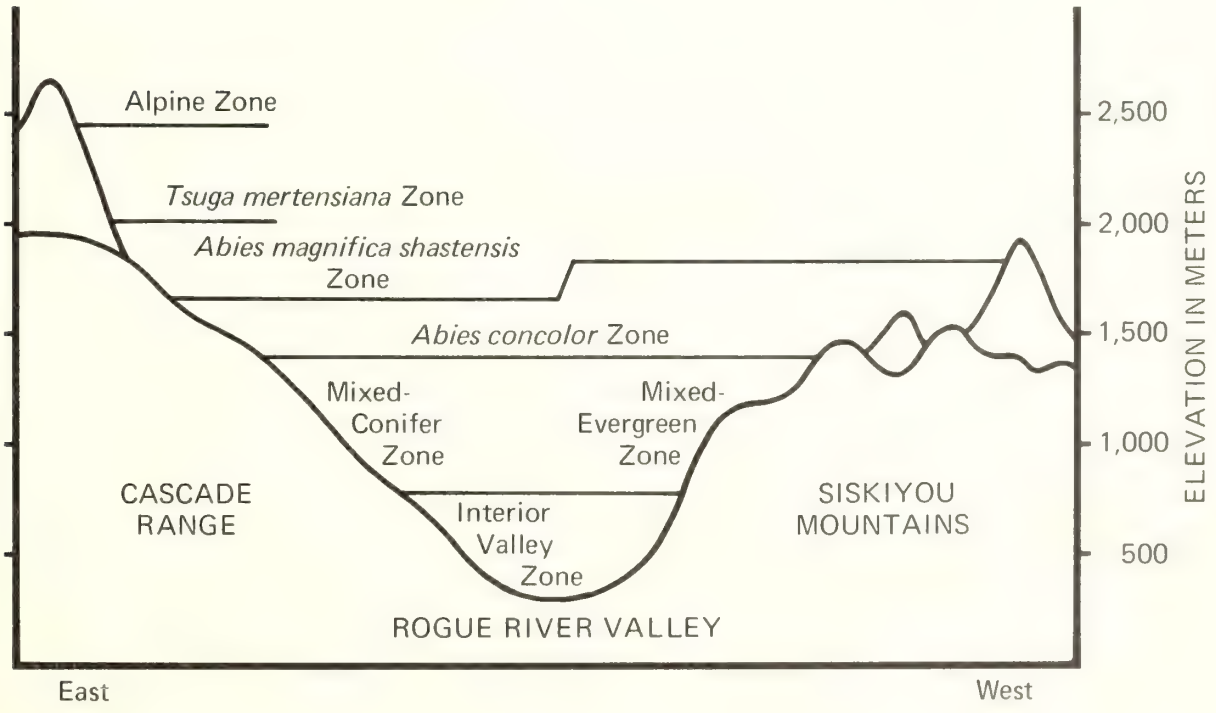


Figure 67. — Arrangement of vegetation zones in the Cascade Range and western Siskiyou Mountains of southwestern Oregon.

INTERIOR VALLEY ("PINUS-QUERCUS-PSEUDOTSUGA") ZONE

"Interior" valleys refer to the valley bottoms and lowlands enclosed by the Cascade Range on the east and the Coast Ranges or Siskiyou Mountains on the west. The major units of this type are the Umpqua, Rogue River, and Willamette valleys. These valley bottoms and adjacent foothills constitute the Interior Valley or *Pinus-Quercus-Pseudotsuga* Zone. Cities, farmlands, and other human developments are a dominant landscape feature. The natural vegetational mosaic includes grasslands, *Quercus* woodlands, coniferous forests, sclerophyllous shrub communities, and riparian types.

The reader should recognize that even though these three major interior valleys share many features in common, there are significant differences between them. Further, this treatment is heavily weighted toward the most mesic, the Willamette valley, because of the near absence of data for the Rogue River and Umpqua valleys. Detling (1968) has taken a different approach typifying vegetation of the Willamette valley as "Pine-oak Forest" and that of the main Umpqua and Rogue valleys as "Chaparral" with a peripheral belt of Pine-oak Forest in the latter.

Environmental Features

The interior valleys of western Oregon are the warmest and driest regions west of the Cascade Range (table 12). This is primarily because they are in the rain shadow of the Coast Ranges or Siskiyou Mountains. This effect is accentuated by their location at the dry end of the general north to south decrease in precipitation and increase in temperature found in western Oregon and Washington. Summers are hot and dry, potential evapotranspiration far exceeding the moisture buildup during the mild, wet winters. There is, of course, a climatic gradient across these valleys; precipitation gradually decreases moving east and down the eastern slopes of the Coast Ranges to a minimum within the valleys, and increases again ascending the western foothills of the Cascade Range. Also, the valleys become increasingly hot and dry from north to south. For example, the Willamette valley is the wettest and the upper Rogue River valley (around Medford, Oregon) is the driest. More locally, the Willamette valley is hotter and drier in the upper valley (around Eugene) than it is 100 miles to the north at its mouth (Portland).

Soils in the Interior Valley Zone include many types found infrequently elsewhere in the Pacific Northwest. Some of the more important great soil groups are the Prairie, Planosol, Alluvial, Reddish Brown Lateritic, and Sols Bruns Acides. Grumusols, swelling, clayey soils dominated by montmorillonite clay, are found in these interior valleys. Lithosolic soils are common on many of the valley foothills, particularly in the Umpqua and upper Rogue River valleys. These shallow rocky soils accentuate the difficulties for vegetation during the droughty summer months.

Community Composition

As mentioned, there is a wide variety of natural and seminatural community types in the Interior Valley Zone. The term "seminatural" is used because the majority have been subjected to major human influences such as logging, clearing, grazing, or burning (or a combination of these). We will consider community composition by individual types (or type groups): *Quercus* woodland, conifer forest, grassland, sclerophyllous shrub, and riparian forest.

Quercus **woodland.** — Forest stands, groves, and savannas dominated by the deciduous oaks, *Quercus garryana* and *Quercus kelloggii*, and by the evergreen *Arbutus menziesii* are a conspicuous feature of the Interior Valley Zone (fig. 68). Thilenius (1964) indicates there are over 400,000 hectares of oak woodlands in northwestern Oregon alone. *Quercus garryana* is often the sole dominant in the Willamette valley, although *Acer macrophyllum*, *Pseudotsuga menziesii*, or *Arbutus menziesii* may be present. *Quercus kelloggii* is found from the southern Willamette valley south. In the Umpqua valley, mixed stands of both *Quercus* spp. and *Arbutus menziesii* are com-

Table 12. — Climatic data from representative stations within the Interior Valley Zone

Area and Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Salem, Oreg.	60	44°55′	123°01′	11.4	3.6	−0.1	19.2	28.0	1,038	55	20
Corvallis, Oreg.	62	44°38′	123°12′	11.3	4.0	.6	18.9	27.1	1,004	47	--
Eugene, Oreg.	110	44°07′	123°13′	11.2	3.7	.1	19.1	27.9	1,040	53	18
Roseburg, Oreg.	154	43°14′	123°22′	12.1	5.2	1.6	19.9	28.0	830	47	17
Grants Pass, Oreg.	282	42°26′	123°19′	12.1	3.9	−.3	21.2	32.3	767	31	17
Medford, Oreg.	400	42°22′	122°52′	12.2	3.0	−1.2	22.3	31.8	497	35	19

Source: U. S. Weather Bureau (1965a).

Figure 68. — Woodlands of *Quercus garryana* and *Q. kelloggii* are typical of the Interior Valley Zone; mosaic of *Quercus* woodland and grassland near Ashland, Oregon, at the head of the Rogue River valley.

Figure 69.– Mixed stands of *Quercus garryana* and *Arbutus menziesii* with scattered *Pseudotsuga menziesii* are typical of many low hills in the Umpqua valley; note the *Rosa eglanteria* and *Rhus diversiloba* in the foreground pasture.

mon, often with scattered *Pseudotsuga menziesii* (Gratkowski 1961a) (fig. 69). In the Rogue River valley, *Quercus garryana* appears to be more important than *Quercus kelloggii* on the most xeric habitats.

Quercus communities have been studied in detail only in the Willamette valley. *Thilenius* (1964, 1968) recognized four major *Quercus garryana* communities in the central valley area and named them after understory dominants: *Corylus cornuta-Polystichum munitum*, *Amelanchier alnifolia-Symphoricarpos albus*, *Prunus avium-Symphoricarpos albus*, and *Rhus diversiloba*. Characteristic understory species for these communities are listed in table 13. The *Corylus cornuta-Polystichum munitum* and *Amelanchier alnifolia-Symphoricarpos albus* are types found on the least disturbed sites. *Prunus avium*, an extremely tolerant introduced shrub or tree, dominates the understory in the third community type. *Prunus avium* saplings often produce nearly impenetrable thickets.

Table 13. — Characteristic species of major *Quercus garryana* communities in the central Willamette valley

Layer	*Corylus cornuta/ Polystichum munitum*	*Amelanchier alnifolia/ Symphoricarpos albus*	*Prunus avium/ Symphoricarpos albus*	*Rhus diversiloba*
Tree	*Quercus garryana* *Acer macrophyllum* *Pseudotsuga menziesii* *Abies grandis*	*Quercus garryana* *Pseudotsuga menziesii* *Acer macrophyllum*	*Quercus garryana* *Pseudotsuga menziesii* *Acer macrophyllum*	*Quercus garryana* *Pseudotsuga menziesii* *Acer macrophyllum*
Tall Shrub	*Corylus cornuta* *Prunus avium*[1] *Amelanchier alnifolia* *Holodiscus discolor* *Osmaronia cerasiformis* *Crataegus douglasii*	*Amelanchier alnifolia* *Osmaronia cerasiformis* *Prunus avium*[1]	*Prunus avium*[1] *Corylus cornuta* *Amelanchier alnifolia*	
Low Shrub	*Polystichum munitum* *Symphoricarpos albus* *Rubus parviflorus* *Rhus diversiloba* *Pteridium aquilinum* *Rubus ursinus* *Rosa eglanteria*[1] *Rosa gymnocarpa*	*Symphoricarpos albus* *Rhus diversiloba* *Polystichum munitum* *Rosa nutkana* *Rosa eglanteria*[1]	*Symphoricarpos albus* *Rhus diversiloba* *Polystichum munitum* *Rubus ursinus*	*Rhus diversiloba* *Rosa eglanteria*[1] *Symphoricarpos albus* *Rubus ursinus*
Herb	*Tellima grandiflora* *Galium* spp.	*Galium* spp.	*Galium* spp.	*Poa pratensis*[1] *Torilis arvensis*[1] *Galium* spp. *Osmorhiza chilensis* *Satureja douglasii* *Fragaria virginiana* var. *platypetala* *Elymus glaucus*

Source: Thilenius (1964).
[1] Exotic species.

Figure 70. — *Quercus garryana* **communities with grass-***Rhus diversiloba* **understories are widespread in the Willamette valley;** *Corylus cornuta* **var.** *californica* **(left foreground) is more common than** *Rhus* **in this 80-year-old stand near Albany, Oregon.**

The *Quercus garryana/Rhus diversiloba* community is most widespread and occupies the most xeric habitats (Thilenius 1964, 1968). It is also found on sites which have been or are heavily grazed and can be the consequence of this grazing. *Rhus diversiloba* occurs in two growth forms — a ground cover and a liana — which are generally connected by a dense, shallow root system. It is generally less palatable to livestock than any of its associates. Thilenius (1964) hypothesized that even if the ground-cover *Rhus diversiloba* is grazed, it can draw on liana *Rhus*, which is out of reach of grazing animals, for photosynthate. He further suggests that once *Rhus diversiloba* has replaced its associates, it maintains dominance even when grazing is stopped.

Thilenius (1964) recognized a *Rhus*-Gramineae variant of the *Rhus diversiloba* community which includes an abundance of herbs (fig. 70) (introduced species are indicated by an asterisk): *Poa pratensis**, *Dactylis glomerata**, *Agrostis tenuis*, *Festuca rubra*, *Torilis arvensis**, *Holcus lanatus**, *Elymus glaucus*, *Danthonia californica*, *Plantago lanceolata**,

*Bromus rigidus**, *Hypericum perforatum**, and *Sanicula crassicaulis*.

Hall (1956) also provides some data on composition of a *Quercus garryana* woodland. Typical species in a relatively undisturbed stand were *Rhus diversiloba*, *Amelanchier alnifolia*, *Ligusticum apiifolium*, *Elymus glaucus*, *Bromus laevipes*, *Osmorhiza chilensis*, *Vicia americana* and *Trisetum cernuum*. Thinning the *Quercus* resulted in an increase in most of these species as well as addition of *Sanicula crassicaulis* and *Fragaria* sp. as important species. Clearing resulted in abundant *Quercus* coppice but increases in only *Rhus diversiloba* and *Elymus glaucus*.

Whittaker (1960) described Oak Woodland as the driest forested formation in his transect across the Siskiyou Mountains. In his driest exemplary locale (adjacent to but not in the Rogue River valley), oak woodlands dominated by an overstory of *Quercus kelloggii* and *garryana* and an understory of grasses occupied east and southeast slopes; *Arbutus menziesii* was absent, but *Ceanothus integerrimus*, *Arctostaphylos viscida*, and *Cercocarpus betuloides* were important high shrubs. Northeastern slopes (more mesic sites) were occupied by open stands of *Pseudotsuga menziesii*, *Pinus ponderosa*, and *Libocedrus decurrens* over a well-developed lower canopy of *Quercus garryana*. *Quercus* coverage decreased and grass coverage increased on increasingly xeric sites, and south or southwest slopes were grassland with only widely scattered *Quercus* spp. or none at all.

Waring (1969) described a Black Oak Type *(Quercus kelloggii)* in the foothills of the eastern Siskiyou Mountains which commonly included *Pseudotsuga menziesii*, *Pinus ponderosa*, *Arbutus menziesii*, and occasional *Quercus garryana*. Typical understory species were *Rhus diversiloba*, *Apocynum pumilum*, *Lonicera hispidula* var. *vacillans*, *Balsamorhiza deltoidea*, *Arctostaphylos viscida*, *Festuca californica*, *Lupinus albifrons*, *Brodiaea multiflora*, *Boschniakia strobilacea*, *Castilleja* spp., *Gilia capitata* and *Plectritis macrocera*.

Obviously, a number of diverse entities are here lumped under "*Quercus* Woodland." They range from very open savannas with grass understories to dense forest stands and from pure *Quercus* types to communities with an abundance of conifer associates, particularly *Pseudotsuga menziesii* and *Pinus ponderosa*. Obviously included are communities both seral and climax. Some of these successional relationships will be considered later in this paper.

Conifer forest. — Coniferous forests occupy large areas of the foothill regions in and around the interior valleys. In the Willamette valley, such stands are widespread and composed mainly of *Pseudotsuga menziesii* (Hansen 1947, Sprague and Hansen 1946, Habeck 1961, Anderson 1967). *Abies grandis* and *Acer macrophyllum* are also widespread components of these stands. *Quercus garryana* and *Arbutus menziesii* may be present, especially as remnants of pioneer stands which prepared the way for the conifers; the intergradation possible between the previously discussed *Quercus*-dominated communities and coniferous-dominated communities should be obvious. Occasionally, *Pinus ponderosa* or *Libocedrus decurrens* may be encountered, the former generally on specialized habitats (coarse alluvial deposits along the river channels) and the latter at the southern end of the valley. *Thuja plicata* is sometimes conspicuous at the northern end of the Willamette valley around Portland.

Further south in the Umpqua valley, *Pseudotsuga menziesii* forest is common on hill crests and more mesic slopes where it is often associated with *Pinus ponderosa* and *Libocedrus decurrens* (Gratkowski 1961a).

The Rogue River valley has perhaps the most diverse valley coniferous forests. *Pseudotsuga menziesii* is still one of the most important species but *Pinus ponderosa*, *Pinus lambertiana*, and *Libocedrus decurrens* are also common (Gratkowski 1961a). *Pinus jeffreyi* woodlands, characteristic of serpentine areas, are also notable, but these will be discussed in a separate section of this paper.

The total community composition of the valley coniferous forests has not been studied in many locations. Those found in the Willamette valley are best known (Sprague and Hansen 1946; Anderson 1967). Anderson (1967) recognized at least two community types which typify some of the foothill coniferous forests: the *Corylus californica/Bromus vul-*

garis and *Acer circinatum/Gaultheria shallon* (*Corylus californica-Holodiscus* subtype) communities. Compositional data for these communities are provided in table 14. It is apparent from a comparison of Anderson (1967) and Thilenius (1964) that most of the understory dominants can be found under both *Quercus garryana* and *Pseudotsuga menziesii* canopies. Some additional comments on understory composition in Willamette valley conifer stands can be found in Sprague and Hansen (1946) and Sabhasri and Ferrell (1960).

The only other coniferous forest data are from the foothills around the Rogue River valley (Whittaker 1960; Waring 1969). Whittaker's (1960) data are hard to interpret, but it appears that he classes low-elevation conifer forests in the western Siskiyou Mountains with the "Mixed Evergreen Formation," *Pseudotsuga*-Sclerophyll in this case. These forests varied greatly with moisture regime but appeared to include: (1) a tree layer of *Pseudotsuga menziesii* (sometimes with *Pinus ponderosa* or *lambertiana* or both); (2) smaller trees of *Castanopsis chrysophylla, Lithocar-*

Table 14. — Characteristic species in two coniferous forest communities found in the foothills of the Willamette valley

Layer	*Corylus californica/Bromus vulgaris*	*Acer circinatum-Gaultheria shallon — Corylus californica-Holodiscus* subtype
Tree	Dominant — *Pseudotsuga menziesii, Abies grandis, Acer macrophyllum* Occasional — *Quercus garryana*	Dominant — *Pseudotsuga menziesii* Occasional — *Abies grandis, Acer macrophyllum, Cornus nuttallii*
Shrub	*Corylus cornuta* var. *californica, Holodiscus discolor, Rosa gymnocarpa, Symphoricarpos albus, Rhus diversiloba*	*Acer circinatum, Corylus cornuta* var. *californica, Holodiscus discolor, Rosa gymnocarpa*
Herb	*Bromus vulgaris, Aster radulinus, Fragaria vesca* var. *bracteata, Satureja douglasii, Vicia americana* var. *truncata, Berberis nervosa, Synthyris reniformis, Madia madioides, Osmorhiza chilensis*	*Gaultheria shallon, Berberis nervosa, Adenocaulon bicolor, Polystichum munitum, Anemone deltoidea, Galium triflorum, Festuca occidentalis*

Source: Anderson (1967).

pus densiflora, *Arbutus menziesii*, and *Quercus kelloggii;* and (3) understory shrubs such as *Quercus chrysolepis*, *Berberis nervosa*, *Rhus diversiloba*, and *Rosa gymnocarpa*. *Ceanothus integerrimus* and *Arctostaphylos viscida* characterized the understory on driest sites. Gratkowski[11] indicates the major conifers on the valley floor in this area are *Pinus ponderosa* and *Libocedrus decurrens* with *Arctostaphylos viscida* and *Ceanothus cuneatus* as understory dominants.

In the floristically poorer eastern Siskiyou Mountains, Waring (1969) recognized a Ponderosa Pine Type as the most xeric of his coniferous types. *Pseudotsuga menziesii*, *Arbutus menziesii*, and, sometimes, *Abies concolor* were associated with the *Pinus ponderosa*. *Arctostaphylos patula*, *A. viscida*, *A. nevadensis*, *Achillea millefolium* var. *lanulosum*, *Solidago canadensis*, *Apocynum pumilum*, and *Lupinus* spp. typified the understory.

Grasslands. — There are extensive areas of grassland in the Interior Valley Zone. Some of these were created by settlers and latter-day farmers through clearing or burning or both (fig. 71). Other grasslands occupy sites that appear incapable of supporting tree growth, e.g., grass balds associated with Grumusols or lithosolic, extremely xeric, southerly exposed slopes. Almost all grassland areas (and *Quercus* savanna) have been heavily grazed by domestic livestock — cattle, sheep, or angora goats — and are extensively used as unimproved pastureland today (fig. 72).

The nature of the original grassland communities is strictly conjectural, since grazing and introduction of alien species have altered all stands to some degree. Turner (1969) has suggested these grasslands probably looked similar to parts of the "California annual-type grassland" with *Danthonia californica* and *Stipa* spp. typical dominant species. Habeck (1961) provided a list of grasses which may have been characteristic of dry and moist sites in the Willamette valley. Species on well-drained sites included *Agrostis hallii*, *Agropyron pauciflorum*, *Bromus carinatus*, *B. vulgaris*, *Danthonia californica*, *Elymus glaucus*, *Festuca octoflora*, *F. californica*, *F. rubra*, *F.*

[11] Personal communication.

Figure 71. — Many of the grasslands in the Interior Valley Zone were created by clearing or burning (or both) of forest lands; burning hill pasture in the Umpqua valley, Oregon.

Figure 72. — Grassland areas in the Interior Valley Zone are heavily grazed. Typically low-lying pasturelands are improved (foreground), and hill grasslands and oak woodland (background) are used as unimproved pasture (near Corvallis, Oregon; *photo courtesy Range Management, Oregon State University*).

occidentalis, *F. subulata*, *Poa scabrella*, *Sitanion jubatum*, and *Stipa lemmonii*. Habeck (1961) suggests a large number of forbs were probably also present on the native prairies.

There are very few descriptive data even for existing valley grasslands, and these are all confined to the vicinity of Corvallis in the Willamette valley (Livingston 1953; Turner 1969; Valassis 1955; Owen 1953), although the general patterns probably have much wider relevance. Typical constituent species are (introduced species are indicated by an asterisk):

Perennial Grasses — *Danthonia californica*, *Festuca rubra*, *F. elatior* var. *arundinacea**, *Agrostis hallii*, *A. tenuis*, *Poa pratensis**, *P. compressa**, *Elymus glaucus*, *Danthonia intermedia*, *Holcus lanatus**, *Stipa columbiana*, *Sitanion hystrix*, *Carex* spp., *Lolium perenne**, *Dactylis glomerata*, *Koeleria cristata*, and *Arrhenatherum elatius**.

Annual Grasses — *Bromus rigidus**, *B. commutatus**, *B. mollis**, *Elymus caput-medusae**, *Cynosurus echinatus**, *Festuca dertonensis**, *F. myuros**, *Avena fatua**, *Aira caryophyllea**, *Briza minor**, and *Gastridium ventricosum**.

Forbs — *Torilis nodosa**, *Daucus carota**, *Ranunculus occidentalis*, *Lactuca serriola**, *Sherardia arvensis**, *Vicia americana*, *V. tetrasperma**, *Erodium cicutarium**, *Hypericum perforatum**, *Taraxacum officinale**, *Fragaria chiloensis*, *Plantago lanceolata**, *Galium divaricatum**, *Veronica peregrina*, *Lathyrus sphaericus**, *Eriophyllum lanatum*, *Hypochaeris radicata**, *Achillea millefolium* var. *lanulosa*, *Sanicula bipinnatifida*.

There is obviously a very high proportion of introduced species in the existing communities; they include all the annual grass dominants. One of these, *Elymus caput-medusae*, is an extremely undesirable species which dominates many stands (Turner et al. 1963; Turner 1969).

Turner (1969) was the only investigator who examined community composition on several sites. *Elymus caput-medusae* and *Danthonia californica* were generally the dominants on his study sites. At one location, Turner thought there might be three grassland types: *Festuca rubra*-dominated on the most mesic habitat, *Stipa columbiana*-dominated on the most xeric, and *Danthonia californica*-dominated on the intermediate habitat. From his descriptions, we would judge that several of the native perennial grasses have considerable ability to resist grazing pressure and persist even though alien annuals are the most widespread dominants.

Livingston (1953) provided a short list of grasses for *Quercus* savanna used as unimproved pasture: *Melica geyeri*, *Dactylis glomerata*, *Poa compressa*, *Lolium perenne*, *Bromus mollis*, *Festuca myuros*, and *Cynosurus echinatus*.

The successional status of valley grasslands hasn't been studied. Scattered bushes of *Rosa eglanteria* and *Rhus diversiloba* are found in many grasslands (fig. 73) and these can become dominant over parts of pasture tract. Some grasslands are readily invaded by *Quercus* spp. (Sprague and Hansen 1946). Other habitats appear to be climax grassland sites, and these include some with relatively deep fine-textured soils as well as Grumusols and xeric lithosolic sites.

Sclerophyllous shrub communities. — Communities of sclerophyllous shrubs are conspicuous in southern interior valleys, especially the Rogue River valley (Gratkowski 1961a) (fig. 74). Very little is known about these communities. Gratkowski (1961a) lists *Ceanothus cuneatus* (especially on the most xeric sites) and *Arctostaphylos viscida* as

Figure 73. — Grasslands are sometimes invaded by *Rosa eglanteria* or *Rhus diversiloba* in the Interior Valley Zone; *Rosa eglanteria* is common in this annual grassland dominated by *Bromus mollis*, *Cynosurus echinatus*, *Lolium perenne*, and *Daucus carota* (*photo courtesy Range Management, Oregon State University*).

Figure 74. — Chaparral is conspicuous in southern interior valleys; *Ceanothus cuneatus* (left) and *Arctostaphylos viscida* (right), on the background slope, are typical in the Rogue River valley and are mixed with *Quercus* spp. in this area.

major brushfield dominants in the valley bottoms. Other characteristic or abundant brushfield species listed by Gratkowski (1961a) are: *Ceanothus integerrimus, C. cordulatus, Rhus diversiloba, R. trilobata,* and *Lithocarpus densiflorus* with *Cornus glabrata* and *Quercus chrysolepis* on moister sites.

Detling (1961, 1968) views at least some of these shrub communities as southern Oregon chaparral, a northern extension of Californian chaparral types. He lists *Ceanothus cuneatus, Arctostaphylos viscida,* and *A. canescens,* as chief constituents of Oregon chaparral, *Ceanothus cuneatus* occupying the most xeric sites. Other chaparral species are *Cercocarpus betuloides, Eriodictyon californicum, Garrya fremontii, Rhamnus californica* var. *occidentalis, Rhus trilobata, Amelanchier pallida,* and *Chrysothamnus nauseosus* var. *albicaulis.* Detling (1961) indicates some chaparral communities are climax (e.g., *Ceanothus cuneatus* on the Rogue River valley floor), whereas others depend on fire for continuance. He found a *Pinus ponderosa/Arctostaphylos canescens* community in the Illinois valley in which *Pinus ponderosa* was believed climax, but indicates none of the chaparral communities (as he defined them) were normally associated with *Pseudotsuga menziesii.*

Riparian communities. — Hardwood forests are typical of riparian habitats and other poorly drained sites subject to annual flooding; however, these plant communities have not been studied. In the Willamette valley, they are typified by *Fraxinus latifolia, Populus trichocarpa, Acer macrophyllum,* and *Alnus rubra,* with an understory of *Salix* spp. (figs. 75 and 76). Similar forests are found elsewhere in the Interior Valley Zone, although *Alnus rhombifolia* tends to replace *Alnus rubra* in more southerly valleys. Extensive, nearly pure stands of *Populus trichocarpa* occupy many of the islands and line the shores along the broad lower Columbia River. In fact, a *Populus trichocarpa* plantation was the first artificially established forest stand in the Pacific Northwest; this stand, planted on an island on the lower Willamette River, has since been harvested for pulpwood.

Successional Relationships

Successional relationships of the communities within the Interior Valley Zone are essentially unknown except in the Willamette valley. Before the Willamette valley was settled, much of it was occupied by prairies and oak savannas (Smith 1949; Habeck 1961). Dense forests were confined primarily to the mountain foothills and flood plains. Indians were probably responsible for most of the fires which created and maintained these open conditions (Kirkwood 1902; Morris 1934).

Figure 75. — *Populus trichocarpa* is typical of riparian sites in the Interior Valley and *Tsuga heterophylla* Zones, often forming pure stands on islands in the Willamette and lower Columbia Rivers (near Wind River, Washington, Gifford Pinchot National Forest).

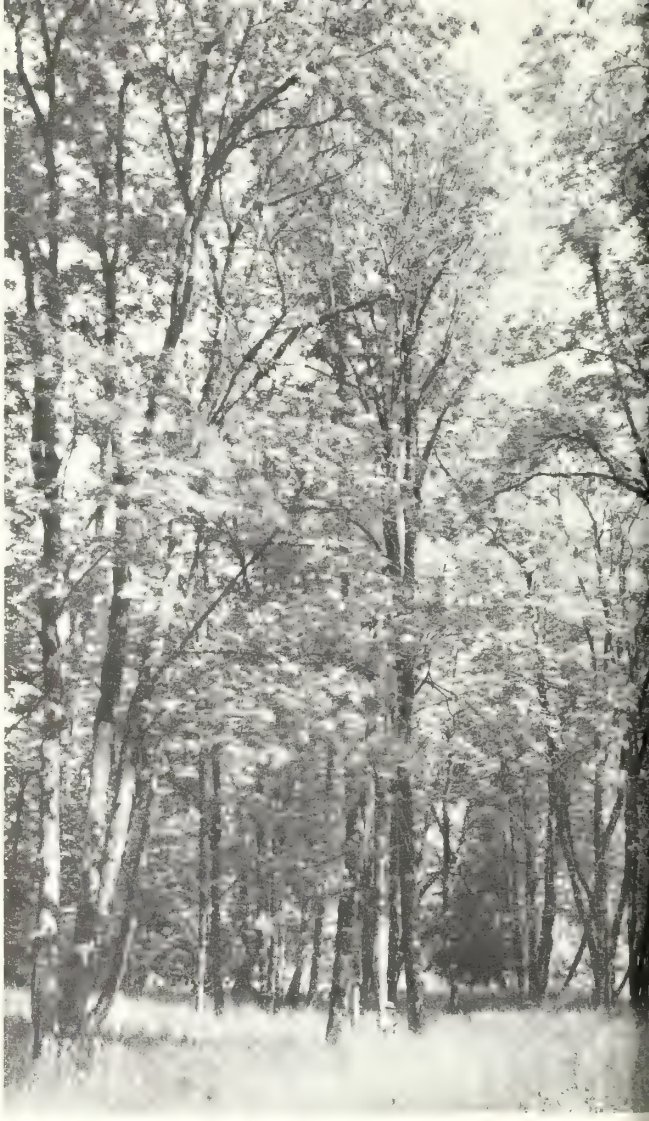


Figure 76. — *Acer macrophyllum* is a common hardwood on both riparian and upland sites in the Interior Valley Zone; this 100-year-old stand is located along the Santiam River near Jefferson, Oregon.

The most notable change since the settlement of the Willamette valley has been the replacement of prairie and *Quercus* savanna by closed *Quercus* forest. Habeck (1961, 1962) has documented this change using land survey records from the 1850's. Thilenius' (1964, 1968) detailed analyses of *Quercus garryana* stands confirm the fact that most closed canopy *Quercus* forests have originated since 1850. He found scattered large trees of open-grown form and averaging 237 years old which were surrounded by smaller *Quercus* of forest-grown form, averaging 74 to 105 years of age.

Fire control activities instituted by the settlers are believed responsible for this major successional change. The hypothesis that open *Quercus* savannas were maintained by fire is strengthened by the fire resistance displayed by large, isolated trees during fall field burnings.

There are various opinions regarding the species which will succeed *Quercus garryana* and constitute the forest climax of the Willam-

ette valley (fig. 77). *Quercus garryana* provides a favorable environment for establishment of *Pseudotsuga menziesii* seedlings (Sprague and Hansen 1946; Collins 1947; Owen 1953). Large *Quercus* often shelter abundant conifer reproduction. Old *Quercus* snags of open-grown form can be found in many foothill *Pseudotsuga menziesii* stands, victims of the conifer seedlings they sheltered (fig. 78). Consequently, Sprague and Hansen (1946) felt *Quercus garryana* stands would be replaced by *Pseudotsuga menziesii* and that these stands might, in turn, be replaced by climax forests of *Abies grandis* or *Abies grandis* and *Pseudotsuga menziesii*. Habeck (1962) agreed that *Pseudotsuga menziesii* was increasing in importance, and *Quercus garryana* was not reproducing under its own canopy. However, he felt that the significance of *Acer macrophyllum* had been overlooked and concluded *Quercus garryana* would be succeeded by *Pseudotsuga menziesii* or *Acer macrophyllum* or both.

Thilenius (1964) concluded that several successional sequences are likely, depending on local conditions. These include replacement of *Quercus garryana* forest by: (1) *Pseudotsuga menziesii* and *Acer macrophyllum*, the former more abundant on drier and the latter on moister sites; (2) *Abies grandis*, either directly or with an interceding stand of *Pseudotsuga;* and (3) *Quercus garryana*, reproduction being sufficient in some communities (especially *Rhus diversiloba*) for it to qualify as climax. Thilenius (1964) also wondered whether the exotic *Prunus avium* might sometimes replace *Quercus* forest; the ability of *Pseudotsuga menziesii* seedlings to develop in understory *Prunus* thickets will be critical.

Successional sequences in the interior valleys to the south (e.g., Umpqua and Rogue River) have not been studied. Some which have been observed are replacement of (1) *Quercus* spp.-*Arbutus menziesii* stands by conifers, (2) *Pinus ponderosa* stands by *Pseudotsuga*, and (3) *Pseudotsuga menziesii* stands by *Abies grandis*. As to the climatic climax species in the Interior Valley Zone, there is evidence for *Abies grandis* in the Willamette valley and *Pseudotsuga menziesii* in the Umpqua valley. In various parts of the Rogue

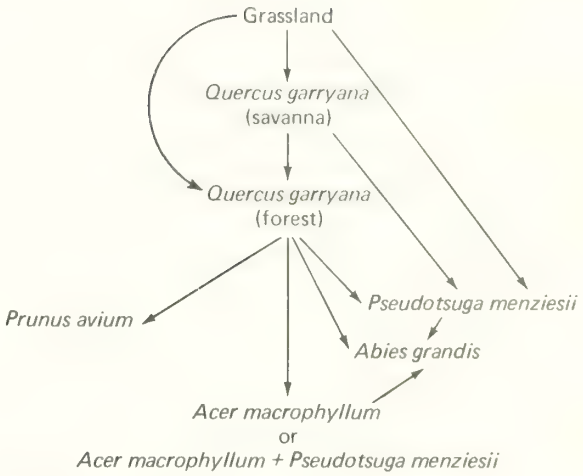


Figure 77. — Successional sequences suggested for upland sites in the central Willamette valley; any of the community types are possible climaxes on selected sites except, perhaps, for *Quercus garryana* savanna (interpreted from Sprague and Hansen 1946; Habeck 1961, 1962; Thilenius 1964).

Figure 78. — Old *Quercus* snags of open-grown form can be found in many Willamette valley *Pseudotsuga menziesii* stands, overtopped and killed by the *Pseudotsuga* reproduction they sheltered (*photo courtesy, Range Management, Oregon State University*).

Figure 79. — Mixed-evergreen forest includes upper stratum of conifers and a lower stratum of sclerophyllous hardwoods; this stand is dominated by *Pseudotsuga menziesii* and *Arbutus menziesii* with an understory of *Lithocarpus densiflorus* (near Oregon Caves, Siskiyou National Forest, Oregon).

River valley, *Pseudotsuga*, *Pinus ponderosa*-*Quercus* spp. and chaparral may be the potential climatic climax.

MIXED-EVERGREEN ("PSEUDOTSUGA"-SCLEROPHYLL) ZONE

In the western Siskiyou Mountains, modal sites are generally occupied by a mixed forest of evergreen needle-leaved trees (upper strata) and sclerophyllous broad-leaved trees (lower strata) (fig. 79). Whittaker (1960, 1961), who has conducted the only significant work in this zone, felt Mixed-Evergreen Forest should be recognized as a major community type of North America.

Environmental Features

Environmentally, this zone is almost unknown. It is relatively warm and wet during the winter months and hot and dry during the summer. Annual precipitation would appear to be between 600 and 1,700 millimeters or more, depending on elevation and distance from the coast. Less than 20 percent falls during the growing season (Gratkowski 1961a). Average annual temperatures of about 47° to 49° F., average July temperatures of 62° to 66° F., and average January temperatures of 32° to 36° F. are likely.

Soils have not been studied, but they are certainly diverse since there is a very wide variety of parent material. Differences in soils have important phytosociologic implications, as shown by Whittaker's (1960) contrasting of vegetation on diorite, gabbro, and serpentine in this area. Major great soil groups present in this zone probably include Reddish Brown Lateritic, Western Brown Forest, and Noncalcic Brown, as well as numerous Lithosols.

Forest Composition

For community descriptions within the Mixed-Evergreen Zone, we are almost entirely dependent upon Whittaker (1960); we will use his description of vegetation growing on diorite, with average moisture conditions as modal for the zone. The upper canopy level is dominated by *Pseudotsuga menziesii*, although *Pinus lambertiana* is frequently present. The lower tree canopy of sclerophyllous trees is dominated by *Lithocarpus densiflorus*, associated with *Quercus chrysolepis*, *Arbutus menziesii*, and *Castanopsis chrysophylla*. The shrub layer averages about 30-percent coverage and is typically composed of *Quercus chrysolepis*, *Berberis nervosa*, *B. pumila*, *Rubus ursinus*, *Rosa gymnocarpa*, *Rhus diversiloba*, and *Gaultheria shallon*. The herbaceous layer is not well developed (6.5-percent coverage) but includes *Whipplea modesta*, *Achlys triphylla*, *Trientalis latifolia*, *Goodyera oblongifolia*, *Pteridium aquilinum*, *Apocynum pumilum*, *Disporum hookeri*, *Lonicera hispidula*, *Festuca occidentalis*, and *Melica harfordii*.

Whittaker (1960) described a *Chamaecyparis lawsoniana-Pseudotsuga menziesii* forest on more mesic sites in which these species are dominants. Small sclerophyllous trees are present but not dominant. *Taxus brevifolia*, *Acer circinatum*, *Corylus cornuta* var. *californica*, and *Cornus nuttallii* are typical understory species along with *Gaultheria shallon*, *Berberis nervosa*, *Rubus ursinus*, *Linnaea borealis*, *Polystichum munitum*, and *Achlys triphylla*.

Whittaker (1960) refers to communities on more xeric dioritic sites as "Sclerophyll-*Pseudotsuga*" as they are characterized by an overgrowth (with less than 50-percent coverage) of *Pseudotsuga menziesii* and a closed canopy of sclerophylls. *Lithocarpus densiflorus* is characteristically the dominant sclerophyll, but *Arbutus menziesii* and *Quercus chrysolepis* are also abundant. Typical shrubs are *Rosa gymnocarpa*, *Rhus diversiloba*, and *Rubus ursinus; Pteridium aquilinum* is the only major herb. Whittaker (1960) indicates he found similar stands without *Pseudotsuga menziesii* or *Pinus lambertiana* on south slopes (*Lithocarpus-Arbutus-Quercus chrysolepis* communities); he felt these were the result of more severe fires since *Pseudotsuga menziesii* seedlings were present. Gratkowski (1961a, b) also mentions extensive tracts of *Lithocarpus-Arbutus* communities in the Siskiyou Uplands and indicates excellent conifer reproduction is often present where a seed source exists.

Vegetation on gabbro was intermediate between that on diorite and on serpentine. The canopy levels were more open. *Umbellularia californica* and *Arctostaphylos cinerea* were added to the sclerophyllous species and *Pinus ponderosa*, *Libocedrus decurrens* and *Pinus lambertiana* were more important than on diorite.

Special Types

Excepting the unique vegetation found on serpentine sites (discussed later), brushfields are the most conspicuous "special communities" found within the Mixed-Evergreen Zone (fig. 80). Many of the large and abundant brushfields found in the Siskiyou Uplands

Figure 80. — Chaparral, forming fields of sclerophyllous shrubs, is very abundant in the Mixed-Evergreen Zone; this typical community is composed of *Arctostaphylos* spp., *Quercus chrysolepis*, and *Ceanothus* spp. (Siskiyou Mountains, Oregon).

(Gratkowski 1961) lie within this zone. Gratkowski (1961a) describes these communities as " . . . dense evergreen chaparrel [which] is part of the Chaparral Association of the Broad Sclerophyll Formation . . . . " Typical constituent species are: *Arctostaphylos canescens*, *A. patula*, *Lithocarpus densiflorus*, *Quercus chrysolepis*, *Q. vaccinifolia*, *Q. sadleriana*, *Castanopsis chrysophylla* var. *minor*, *Garrya fremontii*, *G. buxifolia*, *Rhamnus californica*, *Ribes marshallii*, *Ceanothus cordulatus*, and *Berberis pumila*. Gratkowski (1961b) indicates that communities dominated by *Arctostaphylos patula*, *Ceanothus cordulatus* and *Quercus chrysolepis* are particularly abundant.

The chaparral and forest communities appear to be successionally related in many cases; that is, they are often fire-induced seral types, especially in moist areas (e.g., nearer the coast). Since most shrub dominants sprout after fire, successive burns can eliminate conifers and increase shrub density. On the other hand, chaparral is probably climax on many sites (Gratkowski 1961a): e.g., dry eastern slopes of the Siskiyou Mountains and sites with severe southerly exposures and shallow soils further west. Gratkowski (1961a) feels soil moisture during the dry summer season may be inadequate for tree growth on many of these sites.

MIXED-CONIFER ("PINUS-PSEUDOTSUGA-LIBOCEDRUS-ABIES") ZONE

Mixed forests of *Pseudotsuga menziesii*, *Pinus lambertiana*, *P. ponderosa*, *Libocedrus decurrens*, and *Abies concolor* (or *A. grandis*) typify midelevations in the southwestern Oregon Cascade Range and eastern Siskiyou Mountains. They are northern extensions of the well-known Sierran montane or mixed-conifer forest (Oosting 1956; Küchler 1964). The Mixed-Conifer Zone occurs from about 43° north latitude south along the western flanks of the Cascade Range at elevations of about 750 to 1,400 meters. It is also found in the eastern Siskiyou Mountains, but generally at slightly higher elevations (Waring 1969; Dennis 1959). The Mixed-Conifer Zone is generally bounded by the Interior Valley and the *Abies concolor* Zone at its lower and upper limits, respectively; to the north it grades into the *Tsuga heterophylla* Zone.

Environmental Features

Very few environmental data are available for the Mixed-Conifer Zone except for the eastern Siskiyou Mountains (Waring 1969). Precipitation varies from about 900 to 1,300 millimeters, with very little occurring during the summer months (table 15). Mean temperatures are about the same as in the *Tsuga heterophylla* Zone, but summers are distinctly warmer and drier. Waring (1969) has demonstrated that the moisture regime in mixed-conifer forests is more favorable than in the Ponderosa Pine and Black Oak types discussed earlier.

Forest soils in the Mixed-Conifer Zone of southwestern Oregon are extremely varied due to the complex geological history and topography. Soils typically belong to the Reddish Brown Lateritic, Gray-Brown Podzolic, Western Brown Forest, and Lithosolic great soil groups. Representative Reddish Brown Lateritics have thin organic layers (2 to 5 cm.), dark reddish-brown, slightly acid surface soils and red to dark-red strongly acid subsoils. Organic matter averages only 4 to 5 percent in the surface soil.

Forest Composition

The major forest tree species in the Mixed-Conifer Zone are *Pseudotsuga menziesii*, *Pinus lambertiana*, *P. ponderosa*, *Libocedrus decurrens*, and *Abies concolor*.[1 2] These species occur in many combinations and degrees of mixture (Hayes 1959) (fig. 81). *Pseudotsuga menziesii* is probably the most abundant species, but it tends to decrease and *Pinus* spp. tends

[1 2] The *Abies* under discussion here is part of the *Abies grandis-A. concolor* species complex, widespread in southwestern and eastern Oregon. Southwestern Oregon populations approach *Abies grandis* most closely morphologically; others approach *Abies concolor* morphologically and ecologically (Hamrick 1966). For convenience, we will refer to all of the morphologically variable populations in the Mixed-Conifer and *Abies concolor* Zones as *Abies concolor*.

Table 15. — Climatic data from representative stations within the Mixed-Conifer Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Butte Falls, Oreg.	635	42°32′	122°33′	--	--	--	--	--	931	64	--
Prospect, Oreg.	630	42°44′	122°31′	9.9	1.9	−3.2	19.0	31.1	1,059	62	162
Siskiyou Station, Oreg.	1,295	42°03′	122°36′	9.1	1.3	−3.2	18.4	24.5	863	53	--
Toketee Falls, Oreg.	617	43°16′	122°26′	10.5	1.9	−1.4	20.4	30.4	1,219	85	114

Source: U. S. Weather Bureau (1965a); Johnsgard (1963).

Figure 81. — Major forest trees in the Mixed-Conifer Zone are *Pseudotsuga menziesii*, *Pinus lambertiana*, *Libocedrus decurrens*, *Pinus ponderosa*, and *Abies concolor*; the first three of these are readily identifiable in this typical southwestern Oregon mixed-conifer stand.

to increase in importance from north to south within the zone. *Pinus lambertiana* and *P. ponderosa* usually occur as scattered individuals (Hayes and Hallin 1962) but give the forests much of their character. The proportion of *Libocedrus decurrens* tends to be greatest on relatively xeric sites in this zone. *Abies concolor* is often represented mainly by seedlings and saplings in existing mixed-conifer stands (fig. 82). Other typical tree species include *Acer macrophyllum*, *Arbutus menziesii*, and *Pinus monticola*. *Tsuga heterophylla* and *Thuja plicata* are frequently encountered on more mesic habitats in the northern parts of the Mixed-Conifer Zone. *Castanopsis chrysophylla* may occur as either a shrub or small tree.

Understory communities have not been described within the Mixed-Conifer Zone in the Cascade Range. Reconnaissance data[13] sug-

[13] Unpublished data from studies of the South Umpqua drainage and Abbott Creek Research Natural Area on file with Forestry Sciences Laboratory, Pacific Northwest Forest & Range Exp. Sta., Forest Serv., U. S. Dep. Agr., Corvallis, Oregon.

gest major understory on modal sites is similar to those found on drier sites within the *Tsuga heterophylla* Zone:

Shrub layer – *Rhododendron macrophyllum*, *Corylus cornuta* var. *californica*, *Castanopsis chrysophylla*, *Holodiscus discolor*, *Berberis nervosa*, *B. aquifolium*, *Gaultheria shallon*, *Pachistima myrsinites*, *Rosa gymnocarpa*, *Rhus diversiloba*, and *Vaccinium membranaceum*.

Herb layer – *Rubus ursinus*, *Achlys triphylla*, *Chimaphila umbellata*, *Linnaea borealis*, *Viola sempervirens*, *Trientalis latifolia*, *Synthyris reniformis*, *Whipplea modesta*, *Adenocaulon bicolor*, *Hieracium albiflorum*, *Pyrola picta*, *Pyrola asarifolia*, and *Iris chrysophylla*.

On more mesic sites (e.g., protected draws and north slopes) *Tsuga heterophylla* seedlings, *Taxus brevifolia*, *Cornus nuttallii*, and

Figure 82. – *Abies concolor* **is often represented only by seedlings and saplings in existing mixed-conifer stands, such as this** *Pinus ponderosa* **forest (Rogue River National Forest, Oregon).**

Figure 83. — Forests of *Pseudotsuga menziesii* and *Libocedrus decurrens* often occupy more xeric sites in the Mixed-Conifer Zone; *Libocedrus-Pseudotsuga* stand on steep, south-exposed slopes in the Abbott Creek Research Natural Area (Rogue River National Forest, Oregon).

Figure 84. — *Arctostaphylos nevadensis* and *Ceanothus prostratus* are typical of the many rocky openings found in the Mixed-Conifer Zone (Abbott Creek Natural Area, Rogue River National Forest, Oregon).

Acer circinatum are typically added. The number and coverage of herbaceous species also increases on more mesic sites. Forests of *Pseudotsuga menziesii* and *Libocedrus decurrens* often occupy more xeric sites (fig. 83). *Arctostaphylos nevadensis* and *Ceanothus prostratus* are characteristic understory species on these habitats and in the rocky openings often associated with the xeric forest types (fig. 84).

The Mixed-Conifer forests have been studied in more detail in the eastern Siskiyou Mountains (Waring 1969; Dennis 1959). The same tree species occur there, although *Libocedrus decurrens* appears to be less common than in the Cascade Range. Characteristic understory species are *Corylus cornuta* var. *californica*, *Holodiscus discolor*, *Castanopsis chrysophylla*, *Symphoricarpos mollis*, *Rubus ursinus*, *Rosa gymnocarpa*, *Adenocaulon bicolor*, *Hieracium albiflorum*, and *Senecio integerrimus*.

Successional Patterns

Successional relationships have not been studied in the Mixed-Conifer Zone. It is known that brushfields frequently develop on burned- or logged-over forest lands within the zone (Gratkowski 1961a; Hayes 1959) (fig. 85). Dominants in such communities include *Ceanothus velutinus*, *C. sanguineus*, *C. inte-*

Figure 85. — Brushfields often develop on burned or logged-over lands within the Mixed-Conifer Zone; the Cat Hill brushfield, partially shown here, probably originated after a fire in the 1850's and has since been reburned (near Blue Rock, Rogue River National Forest, Oregon).

gerrimus, *C. prostratus*, *C. cordulatus*, *Castanopsis chrysophylla*, *Quercus chrysolepis*, *Amelanchier alnifolia*, *Arctostaphylos canescens*, and *Lithocarpus densiflorus* (Gratkowski 1961a). These brushfield communities can significantly slow the rate of forest succession or, with repeated fire, become semipermanent communities.

Ceanothus velutinus is important as a brushfield dominant or invader following logging or fire in the Mixed-Conifer Zone as well as many other zones: e.g., in parts of the *Tsuga heterophylla* (Morris 1958; Zavitkovski 1966), *Abies concolor*, and *A. magnifica shastensis* Zones, and in many of the forest types of eastern Oregon and Washington (Dyrness and Youngberg 1966; Mueggler 1965). In western Oregon, *Ceanothus velutinus* var. *laevigatus* and var. *velutinus* are generally found below and above 800 meters, respectively (Gratkowski 196la; Zavitkovski 1966). In this area, *Ceanothus velutinus* is generally absent from understories of older stands lacking recent disturbance, but it often appears in abundance following logging and slash burning (Morris 1958) (fig. 86). This reproduction is from seed stored in the forest floor (Gratkowski 1962); heat from fires and increased insolation breaks the seedcoat dormancy. The relationship of *Ceanothus velutinus* to establishment and growth of coniferous reproduction has been hotly debated for 50 years (Zavitkovski and Newton 1968). It can fix nitrogen (Wollum 1962, 1965; Wollum et al. 1968), and may provide a favorable microenvironment for establishment of conifer seedlings under some conditions (Gratkowski 1962; Zavitkovski and Newton 1968). On other sites, it may seriously hinder establishment of coniferous stands.

Successional relationships among the tree species are not completely known. Many stands are relatively young and/or have been subjected to one or more fires since their establishment. *Pinus lambertiana* is seral, but long-lived; reproduction occurs sporadically in stands and small openings (fig. 87). *Pinus ponderosa* is also seral, although it may achieve climax status on poorly drained sites (Stephens 1965) and on extremely xeric sites. *Pseudotsuga menziesii*, the major forest dominant, is normally seral except on xeric sites,

Figure 86. — After forest lands have been logged and burned, *Ceanothus velutinus* reproduces from seed stored in the soil, despite its general absence from understories of older stands; it frequently hinders establishment and growth of conifer seedlings in the Mixed-Conifer Zone.

Figure 87. — Small openings are typical of mature mixed-conifer forests and provide opportunities for regeneration of less tolerant species; *Pseudotsuga menziesii*, *Pinus lambertiana*, *Abies concolor*, and *Lithocarpus densiflorus* seedlings are present in this opening (Abbott Creek Research Natural Area, Rogue River National Forest, Oregon).

where it may join *Libocedrus decurrens* in maintaining self-perpetuating populations. *Abies concolor* (or *A. grandis*) appears to be the major climax species within the Mixed-Conifer Zone; it is the most tolerant species normally present and dominates the conifer reproduction (fig. 82).

Unfortunately, we cannot outline further the diversity of forest and other communities found within the Mixed-Conifer Zone due to lack of data. Future research will doubtless illustrate the varied and complex plant communities within this zone.

Figure 88. — *Abies concolor* forests are especially extensive and well developed along the southern and southwestern flanks of the Oregon Cascade Range; this pure *Abies concolor* forest is typical of those found near Mount McLoughlin (Rogue River National Forest, Oregon).

"ABIES CONCOLOR" ZONE

Forests dominated by *Abies concolor* are the major feature of the *Abies concolor* Zone. This zone grades into the Mixed-Conifer and *Abies magnifica shastensis* Zones at its lower and upper limits, respectively. It occupies a relatively narrow elevational band, occurring at about 1,400 to 1,600 meters in the Cascade Range and 1,650 to 1,800 meters and 1,400 to 1,800 meters in the eastern and western Siskiyou Mountains, respectively (Waring 1969; Whittaker 1960). However, around Lake of the Woods and along the southwestern flank of the southern Oregon Cascade Range, there are extensive tracts at the appropriate elevations, and consequently, *Abies concolor* forests are widespread and well developed there (fig. 88). The *Abies concolor* Zone of southwestern Oregon extends around the southern end of the Cascade Range into southeastern Oregon, an area discussed later. It correlates with the "White Fir Phase" of the Mixed-Conifer Forest in northern California (Griffin 1967) and is considered an element of Merriam's Canadian Life Zone (Dennis 1959).

Environmental Features

Climatic and edaphic data for the *Abies concolor* Zone are not available. The zone does experience lower temperatures, less plant moisture stress (Waring 1969), and less soil drought (Griffin 1967) than the adjacent Mixed-Conifer Zone. It is the lowest zone where significant winter snow accumulations occur; Waring (1969) mentioned that heavy snowfalls are damaging to brittle-limbed species such as *Pinus ponderosa* and *Arbutus menziesii*. Major soil types include Gray-Brown and Brown Podzols.

Forest Composition

Abies concolor is the major tree species within the *Abies concolor* Zone, often forming pure or nearly pure stands (fig. 88). The most common associate is *Pseudotsuga menziesii*. *Pinus lambertiana*, *P. ponderosa*, and *P. monticola* may be present in small numbers. *Libocedrus decurrens* is often associated on

mesic sites. *Abies magnifica* var. *shastensis* is increasingly common toward the upper limits of the *Abies concolor* Zone. *Pinus contorta* is encountered as a pioneer species in the Cascade Range.

Characteristic understory species in *Abies concolor* forests are (Whittaker 1960; Waring 1969; Dennis 1959):

Shrubs — *Holodiscus discolor*, *Rosa gymnocarpa*, *Berberis nervosa*, *Corylus cornuta* var. *californica*, *Acer glabrum* var. *douglasii*, *Rubus ursinus*, *R. nivalis*, *Amelanchier alnifolia*, and *Castanopsis chrysophylla*.

Herbs — *Campanula scouleri*, *Lathyrus polyphyllus*, *Anemone deltoidea*, *Achlys triphylla*, *Trientalis latifolia*, *Tiarella unifoliata*, *Galium triflorum*, *Adenocaulon bicolor*, *Vancouveria hexandra*, *Clintonia uniflora*, *Trillium ovatum*, *Hieracium albiflorum*, *Arenaria macrophyllum*, *Phacelia heterophylla*, and *Fragaria vesca* var. *bracteata*.

Successional Patterns

Abies concolor appears to be the sole climax species on modal habitats (fig. 89). *Libocedrus decurrens* may be a climax associate on more mesic habitats and *Pseudotsuga menziesii* or *Libocedrus decurrens* or both on xeric habitats.

Special Types

A variety of nonforested communities is found in the *Abies concolor* Zone. Brushfields similar to those found in the Mixed-Conifer Zone are encountered. *Ceanothus velutinus* remains a typical dominant, and *Ribes* spp. appear increasingly in the Cascade Range. *Arctostaphylos patula* is a major shrubby associate in the eastern Siskiyou Mountains (Dennis 1959).

Many different kinds of mountain meadows and barren openings are also found within the *Abies concolor* and adjacent *Abies magnifica shastensis* Zones. The compositions of these various meadow communities are not known. There is extensive evidence of invasion of many of these meadows by tree species. *Libocedrus decurrens* is conspicuous as a pioneer tree in many areas (fig. 90); e.g.,

Figure 89. — *Abies concolor* appears to be the sole climax species on modal sites in the *A. concolor* Zone; *Abies concolor* regeneration completely dominates under this mixed stand of *A. concolor*, *A. magnifica* var. *shastensis*, and *Libocedrus decurrens*.

Figure 90. — Invasion of meadows by *Libocedrus decurrens* is common within the *Abies concolor* Zone (Abbott Creek Research Natural Area, Rogue River National Forest, Oregon).

along the divide between the Rogue and Umpqua Rivers and on the high ridges within the Umpqua River drainage.

"ABIES MAGNIFICA SHASTENSIS" ZONE

Abies magnifica var. *shastensis*[14] dominates the forests between the subalpine *Tsuga mertensiana* Zone and the *Abies concolor* Zone (fig. 91). The *Abies magnifica shastensis* Zone is generally found at elevations between 1,600 and 2,000 meters in the Cascade Range and 1,800 and 2,200 meters in the Siskiyou Mountains (Dennis 1959; Whittaker 1960). It is well developed on the western slopes of the Cascade Range; e.g., in the vicinity of Crater Lake National Park. The forests of this zone are closely allied with *Abies magnifica* or Red Fir forests of the California Cascade Range and Sierra Nevada (Oosting and Billings 1943; Küchler 1964; Griffin 1967). They are generally considered a part of Merriam's Canadian Life Zone (Bailey 1936; Dennis 1959).

Environmental Features

Environmental data are lacking for the *Abies magnifica shastensis* Zone. The Crater Lake climatic station (table 10) is near its boundary with the *Tsuga mertensiana* Zone. Two major climatic features are known: (1) much of the annual precipitation falls as snow, which accumulates in winter snowpacks with maximum depths of 2 meters or more; (2) critical plant moisture stresses do not occur during the short summers (Waring 1969; Griffin 1967). Soils tend towards Brown Podzolic types with well-developed mor humus layers; podzolic A2 horizons are not encountered, however.

Forest Composition

Abies magnifica var. *shastensis* is the major tree species within the *Abies magnifica shastensis* Zone (fig. 91). *Abies concolor*, *Pinus monticola*, *P. contorta*, and *Tsuga mertensiana* are the most common associates. Many other species are not common but may be present, especially on specialized habitats, including *Pseudotsuga menziesii*, *Pinus ponderosa*, *Libocedrus decurrens*, *Picea engelmannii*, *Abies amabilis*, and *A. lasiocarpa*.

The understory in *Abies magnifica* var. *shastensis* stands is highly variable in density. Under dense forest stands, it may be nearly absent and include only Oosting and Billings' (1943) ericaceous and saprophytic "*Pirola-Corallorrhiza* union": *Chimaphila umbellata*, *C. menziesii*, *Pyrola secunda*, *P. picta*, *Corallorrhiza maculata*, *Pterospora andromedea*,

Figure 91. — Pure, even-aged stands of *Abies magnifica* var. *shastensis* are common within the *A. magnifica shastensis* Zone of southwestern Oregon (Rogue River National Forest, Oregon).

[14] Taxonomic controversy surrounds this southern Oregon *Abies* (Franklin 1964). It has been referred to as both *Abies procera* and *A. magnifica* var. *shastensis*. Populations in southwestern Oregon appear to be part of a species complex involving *Abies procera* and *A. magnifica*; it has been suggested these constitute hybrid populations between these species. For convenience, we will refer to these populations as *Abies magnifica* var. *shastensis* which they resemble ecologically. Although Whittaker (1960) referred to his populations as *Abies nobilis* (synonym for *A. procera*), he stated (personal communication) that elements of *Abies magnifica*, *A. magnifica* var. *shastensis*, and *A. procera* were all present.

and *Sarcodes sanguinea*. In other cases, the understory is relatively rich, especially in herbs; typical species are (Waring 1969; Whittaker 1960; Dennis 1959):

Shrubs — *Vaccinium membranaceum*, *Ribes marshallii*, *R. viscosissimum*, *Arctostaphylos patula*, *A. nevadensis*, and *Castanopsis chrysophylla*.

Herbs — *Anemone deltoidea*, *A. oregana*, *Valeriana sitchensis*, *Arenaria macrophylla*, *Campanula scouleri*, *Achlys triphylla*, *Arnica latifolia*, *A. cordifolia*, *Osmorhiza chilensis*, *Hieracium albiflorum*, *Viola glabella*, *Polemonium californicum*, and *Stellaria crispa*.

Successional Patterns

Successional relationships in the *Abies magnifica shastensis* Zone are not completely understood. Any of the tree species may invade an area directly following fire or logging, but *Pinus contorta* and *P. monticola* are confined strictly to a seral role on normal forest sites. Interesting two-storied stands of scattered old *Abies magnifica* var. *shastensis* over a *Pinus contorta* lower canopy are sometimes encountered; reproduction of *Abies magnifica* var. *shastensis* is typically present within the understory.

Abies magnifica var. *shastensis* exhibits varied behavior. In many stands it appears to be climax; i.e., it is reproducing in sufficient numbers to maintain the population. In other areas, *Abies magnifica* var. *shastensis* stands are apparently succeeded by *Abies concolor* or *Tsuga mertensiana* (particularly at the lower and upper limits of the zone, respectively), or even by *Abies amabilis* (on some protected sites toward the north end of the zone). This variable behavior is interesting since *Abies magnifica* is the major climax species in the Sierran *Abietum magnificae* (Oosting and Billings 1943), whereas *Abies procera* is never climax in the northern Cascade Range (Franklin 1966; Thornburgh 1969).

Special Types

Brushfields are encountered with the *Abies magnifica shastensis* Zone. *Ribes* spp., *Vaccinium membranaceum*, and *Ceanothus velutinus* are typical dominants. Dennis (1959) described two shrub communities within this zone in the eastern Siskiyou Mountains — *Arctostaphylos patula/Ceanothus velutinus* and *Artemisia tridentata/Lonicera conjugialis*. Both included scattered *Abies magnifica* var. *shastensis* and *Pinus monticola*. Shrub communities dominated by *Cercocarpus ledifolius* are also encountered in the Siskiyou Mountains.

A variety of wet and dry meadow communities is associated with the *Abies magnifica* var. *shastensis* forest, as mentioned earlier. No data are available on the extent or composition of these communities.

Eastern Oregon and Washington

Conifer forests are conspicuous in the dry interior regions. They clothe the eastern slopes of the Cascade Range and extend, with only minor interruptions, around the northern edge of Washington to the northern Rocky Mountains. Forests also dominate in the Blue, Ochoco, and Wallowa Mountains of Oregon.

In this region, elements of the continental Rocky Mountain forests meld with some of those from coastal areas. In addition, forest species mix with species from steppe and shrub-steppe communities, especially near lower timberline. It is a country typified by the "western yellow pine" (*Pinus ponderosa*) forests.

Forests of the interior region have been studied by foresters and ecologists for many years. Shantz and Zon (1924) and Hansen (1947) provided generalized accounts. Notable synecological studies include those of Daubenmire (1952, 1953, 1956, 1966), Daubenmire and Daubenmire (1968), Driscoll (1962, 1964a, 1964b), Hall (1967), Berry (1963), Dyrness and Youngberg (1958, 1966), Swedberg (1961), Trappe and Harris (1958), Volland (1963), West (1964, 1969), and McMinn (1952). Weaver (1943, 1955, 1959, 1961, 1964, 1968) has written extensively about the role of fire in these forests. The intricate relationship between *Pinus ponderosa* and *Pinus contorta* in the central Ore-

gon pumice region has received special consideration by Kerr (1913); Munger (1914); Tarrant (1953); Youngberg and Dyrness (1959); and Berntsen (1967).

Through these studies, many forest associations have been identified, characterized by different climax tree species: *Juniperus occidentalis*, *Pinus ponderosa*, *Pseudotsuga menziesii*, *Abies grandis*, *Thuja plicata*, *Tsuga heterophylla*, *Abies lasiocarpa*, *Pinus contorta*, and *Libocedrus decurrens*. *Abies concolor*[15] and *Abies magnifica* var. *shastensis*[16] associations, so widespread in California and southwestern Oregon, are also encountered on eastern slopes of the southern Oregon Cascade Range. At higher elevations, near the crest of the Cascade Range, occur *Tsuga mertensiana* and sometimes *Abies amabilis* associations. These have already been discussed.

This abundance of climax forest types and the complex array of seral communities result from an abundance of coniferous species and environmental diversity. Climax associations are generally arrayed elevationally as zones, the consequence of differing responses of tree species to temperature and moisture gradients interacting with differing degrees of tolerance. Daubenmire (1966) has illustrated this phenomenon for forests of eastern Washington and northern Idaho (fig. 92). At various points along the gradient, increasingly tolerant species enter the forest communities producing a sequence of steps based on the climax tree species.

For discussion of interior forests we will group the series of climax associations into seven zones:

Juniperus occidentalis
Pinus ponderosa
Pinus contorta
Pseudotsuga menziesii (plus *Libocedrus decurrens*)
Abies grandis (plus *Abies concolor*)
Tsuga heterophylla (plus *Thuja plicata*)
Abies lasiocarpa

[15] *Abies grandis* and *Abies concolor* form a continuously varying biological complex in eastern Oregon. Most of the *Abies grandis* found in northeastern Oregon (Blue Mountains and Cascade Range) intergrades with *Abies concolor*. In this area we will, for convenience, refer to the populations as *Abies grandis* since the complex resembles this species morphologically. In south-central Oregon, we will refer to the complex as *Abies concolor*. These two species and the zones they typify occupy analogous positions synecologically and environmentally in their respective "areas."

[16] See footnote 14.

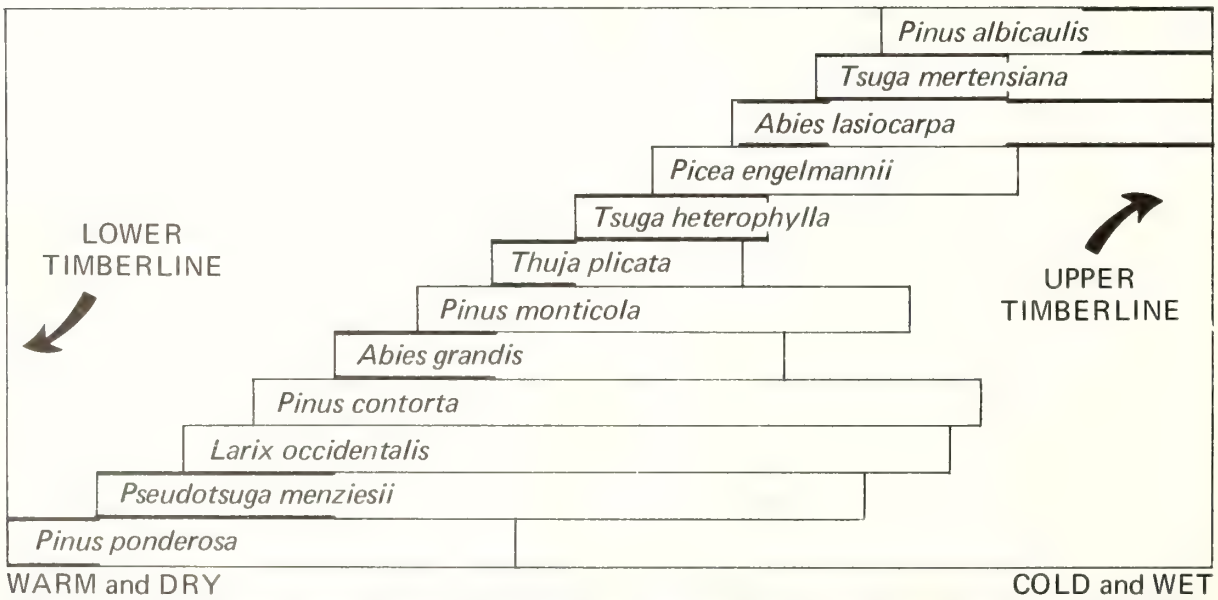


Figure 92. — Coniferous trees in eastern Washington and northern Idaho showing the usual order in which the species are encountered with increasing altitude; horizontal bars designate upper and lower limits of species relative to the climatic gradient, portions of a species range where it is climax in the face of intense competition indicated by heavy lines (from Daubenmire 1966).

All of these zones delineate important phytogeographic units, but they do not occur on a single mountain slope nor do they necessarily occur as sequential belts. The *Pinus contorta* Zone does not really qualify as part of a zonal series since *P. contorta* does not occur as a climatic climax. However, since climax *Pinus contorta* forests are so conspicuous in parts of eastern Oregon, they are treated at the zonal level.

Typical zonal sequences at various locations in eastern Oregon and Washington are indicated in table 16. Obviously, a great variation is possible. Lack of a zone in a particular area can result from species absence, the consequence of macroclimate or history, or from localized edaphic conditions. For example, in northern Idaho, *Tsuga heterophylla*, *Thuja plicata*, and *Abies grandis* are all common (Daubenmire and Daubenmire 1968). To the south, along the Rocky Mountains within Idaho, *Tsuga*, *Thuja*, and finally *Abies grandis* drop out in turn, gradually altering the zonal sequence. Similarly, *Tsuga heterophylla* and *Thuja plicata* are absent from the eastern slopes of the southern Oregon Cascade Range and Blue Mountains, whereas *Juniperus occidentalis* is generally absent from eastern Washington. Examples of the influence of localized edaphic and climatic conditions include the *Pinus ponderosa-Pinus contorta* complex on Mazama pumice in south-central Oregon and the tendency on finer textured soils for elimination of a *Pinus ponderosa* Zone between steppe and the *Pseudotsuga menziesii* Zone (as illustrated by Brayshaw 1965).

A most important regional variation in zonal sequences involves the relative importance of the *Abies grandis* and *Pseudotsuga menziesii* Zones. The *Abies grandis* Zone (including *Abies concolor*) is probably the most extensive forested zone in eastern Oregon; the *Pseudotsuga menziesii* Zone is poorly represented or absent. Conversely, on eastern slopes of the northern Washington Cascade Range and in the Okanogan Highlands, the *Pseudotsuga menziesii* Zone becomes relatively more important than the *Abies grandis* Zone until, in adjacent British Columbia, the latter is absent (Brayshaw 1965).

Table 17 provides an overview of forest composition and successional relationships in the forested zones of eastern Oregon and Washington.

"JUNIPERUS OCCIDENTALIS" ZONE

The *Juniperus occidentalis* Zone is the northwestern representation of the Pinyon-Juniper Zone so conspicuous in the Great Basin region (Billings 1951). It is generally a savanna zone (fig. 93), occupying habitats intermediate in moisture between *Pinus ponderosa* forest and steppe or shrub-steppe (Driscoll 1964b). The *Juniperus occidentalis* Zone is found only in eastern Oregon, reaching maximum development in central Oregon around the Deschutes, Crooked, and John Day Rivers. Similar communities occur at various localities throughout southeastern Oregon; Driscoll (1964b) has suggested a physiographic subdivision of the zone into three units based on soil parent materials. Elevational range of the zone appears to be between about 760 and 1,400 meters, although most stands Driscoll (1964b) sampled were between 1,200 and 1,400 meters.

Environmental Features

The *Juniperus occidentalis* Zone is the most xeric of the tree-dominated zones in the Pacific Northwest. Annual precipitation is low. At Bend, in the *Pinus ponderosa-Juniperus occidentalis* transition, it averages 312 millimeters, but in the center of the zone 200 to 250 millimeters is typical (table 18). Most precipitation falls during the winter, and the hot summer months are often completely dry.

The zone includes Sierozem, Brown, and Chestnut great soil groups (Driscoll 1964b). Brown soils and associated Regosols are most common. Surface soils are typically light colored, coarse textured (sandy loams), low in organic matter (e.g., 1 to 4 percent), and slightly acid (pH 6.0) to neutral. Soils average around 76 centimeters in depth, although roots may penetrate underlying cracked bedrock. Subsoils typically have white calcareous or siliceous deposits on peds or rocks.

Table 16. — Typical zonal forest sequences at locations in eastern Washington and Oregon adapted from the indicated sources[1]

Northwestern Washington and northern Idaho (Daubenmire 1952, 1966)	Eastern slopes, Washington Cascade Range (Franklin and Trappe 1963)	Eastern slopes, central Oregon Cascade Range (Swedberg 1961; West 1964)	Eastern slopes, southern Oregon Cascade Range (Dyrness and Youngberg 1958, 1966)	Ochoco and Blue Mountains, Oregon (Hall 1967)
		Juniperus occidentalis	*Juniperus occidentalis*	*(Juniperus occidentalis)*
Pinus ponderosa	*(Pinus ponderosa)*	*Pinus ponderosa*	*Pinus contorta*	*Pinus ponderosa*
Pseudotsuga menziesii	*Pseudotsuga menziesii*	*(Pseudotsuga menziesii)*	*Pinus ponderosa*	
Abies grandis	*Abies grandis*	*Abies grandis*	*Abies concolor*	*Abies grandis*
Tsuga heterophylla	*(Tsuga heterophylla* and/or *Abies amabilis)*	*(Abies amabilis)*	*(Abies magnifica* var. *shastensis)*	
Abies lasiocarpa or *Tsuga mertensiana*	*Abies lasiocarpa* or *Tsuga mertensiana*	*Tsuga mertensiana*	*(Tsuga mertensiana)*	*(Abies lasiocarpa)*

[1] Species names in parentheses indicate the enclosed zone may be absent or only fragmentally represented.

Table 17. — Importance and ecological role of major tree species in representative forest zones and locales in eastern Oregon and Washington[1]

Species	Eastern Washington Cascade Range					Central Oregon Cascade Range					Ochoco and Blue Mountains	
	Pinus ponderosa Zone	*Pseudotsuga menziesii* Zone	*Abies grandis* Zone	*Tsuga heterophylla* Zone	*Abies lasiocarpa* Zone	*Juniperus occidentalis* Zone	*Pinus ponderosa* Zone	*Pseudotsuga menziesii* Zone	*Abies grandis*[2] Zone	*Tsuga mertensiana* Zone	*Pinus ponderosa* Zone	*Abies grandis*[2] Zone
Abies amabilis	—	—	—	—	c	—	—	—	—	c	—	—
Abies grandis	—	—	C	S	s	—	—	—	C	s	—	C
Abies lasiocarpa	—	—	—	s	C	—	—	—	s	C	—	—
Libocedrus decurrens	—	S	S	s	s	—	—	c	s	—	—	—
Larix occidentalis	—	S	S	s	s	—	—	s	s	—	—	S
Larix lyallii	—	—	—	—	s	—	—	—	—	—	—	—
Picea engelmannii	—	—	s	s	Sc	—	—	—	s	s	—	s
Pinus contorta	—	S	S	s	s	—	—	s	S	S	—	S
Pinus lambertiana	—	—	—	—	—	—	—	—	s	—	—	—
Pinus monticola	—	—	S	S	s	—	—	—	s	s	—	s
Pinus ponderosa	C	S	S	s	—	—	C	S	S	s	C	s
Juniperus occidentalis	—	—	—	—	—	C	s	s	—	—	s	—
Populus tremuloides	s	s	s	—	—	—	s	s	s	—	—	—
Pseudotsuga menziesii	—	C	S	S	s	—	—	C	S	s	—	Sc
Thuja plicata	—	—	—	sc	—	—	—	—	—	—	—	—
Tsuga heterophylla	—	—	—	C	s	—	—	—	—	—	—	—
Tsuga mertensiana	—	—	—	—	c	—	—	—	s	C	—	—

[1] C = major climax species, c = minor climax species, S = major seral species, and s = minor seral species.

[2] *Abies grandis-A. concolor* complex.

Table 18. — Climatic data from representative stations within the *Juniperus occidentalis* zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Bend, Oreg.	1,097	44°04′	121°19′	8.0	–0.9	–6.5	17.9	28.7	318	50	92
Redmond, Oreg.	913	44°17′	121°10′	9.1	–.1	–5.9	18.8	29.5	216	42	61
Prineville, Oreg.	866	44°21′	120°54′	8.0	–.56	–6.6	18.1	29.8	238	41	35

Source: U. S. Weather Bureau (1965a).

Figure 93. — The *Juniperus occidentalis* Zone is primarily a savanna region, ecotonal between *Pinus ponderosa* forest and *Artemisia* shrub-steppe (near Bend, Oregon).

Community Composition

Driscoll (1962, 1964a, 1964b) has provided the only comprehensive description of communities in the *Juniperus occidentalis* Zone. His general description of the vegetation of the zone is as follows (Driscoll 1964b):

> *Juniperus occidentalis* is the dominant tree species of the area. An occasional *Pinus ponderosa* may be found in canyon bottoms or on north slopes where soil moisture is more effective. Natural wide spacing of individual junipers provides the aspect of a savanna .... *Artemisia tridentata* is most often the dominant shrub in the understory. Occasionally it is displaced wholly or to codominance by *Purshia tridentata*. Other shrubs characteristic of the area are *Chrysothamnus nauseosus*, *C. viscidiflorus*, *Tetradymia canescens*, *Leptodactylon pungens*, and *Artemisia arbuscula*. *Ribes cereum*, *Grossularia velutina*, *[Ribes velutinum]*, and *Grayia spinosa* occur infrequently. Suffrutescents are represented by various species of *Eriogonum*.

Agropyron spicatum and *Festuca idahoensis* are the characteristic grasses of relatively undisturbed communities. *Poa secunda* and *Stipa thurberiana* are common. Other grasses include *Sitanion hystrix*, *Stipa comata*, *Bromus tectorum*, *Festuca octoflora*, and *Koeleria cristata*.

Forbs commonly do not constitute major components of relatively undisturbed communities. Some of the more common perennial forbs are *Agoseris* sp., *Achillea millefolium*, *Eriophyllum lanatum*, *Astragalus* spp., *Erigeron linearis*, and *Lupinus* spp.

From the 11 associations and variants described by Driscoll (1964a, 1964b), we can pick five which typify major variations in *Juniperus occidentalis* communities (table 19). The *Juniperus/Artemisia/Agropyron* association was found on well-drained loamy soils on undulating topography; hence, its climatic climax designation. *Artemisia tridentata* (average maximum height 0.6 m.) and *Agropyron spicatum* typified the shrub and herb components, both attaining maximum status here. *Chrysothamnus nauseosus* was the only other shrub. *Stipa thurberiana, Poa secunda, Lomatium triternatum, Bromus tectorum,* and *Festuca octoflora* were other notable species.

The *Juniperus/Festuca* association was notable for its high coverage of *Juniperus occidentalis* and *Festuca idahoensis* and low shrub cover (table 19). The shrub cover was lowest in the *Juniperus/Agropyron* association. The *Juniperus/Artemisia-Purshia* association was lowest in *Juniperus occidentalis* and highest in shrub coverage (*Artemisia tridentata* and *Purshia tridentata).* The *Juniperus/Artemisia/Agropyron-Astragalus* association (fig. 94) occupied the most xeric sites. *Festuca idahoensis* was found only in *Juniperus* shade in this association. Of the few perennial herbs, *Astragalus lectulus* was quite specific to this association.

Succession

Very little is known concerning successional relationships in the *Juniperus occidentalis* Zone. Burning can kill *Juniperus occidentalis* and temporarily produce an herb- or shrub-dominated community which is gradually reinvaded by trees. Sparsity of *Juniperus occidentalis* in some associations was explained in this way (Driscoll 1964b). The fire-sensitive *Purshia tridentata* is similarly affected. Grazing by cattle can result in a reduction of the preferred *Agropyron spicatum* and *Festuca idahoensis*; deer browsing affects primarily the *Purshia tridentata* and *Juniperus.*

"PINUS PONDEROSA" ZONE

Pinus ponderosa forests are widely distributed in eastern Oregon and Washington. They occupy: (1) a narrow band (15 to 30 km. wide) on the eastern flanks of the entire Cascade Range (generally); (2) much of the high pumice plateau extending east from the High Cascades province; (3) large areas in the Blue Mountains province (Ochoco, Blue, and Wallowa Mountains) of northeastern Oregon and extreme southeastern Washington; and (4) extensive tracts in the Okanogan Highlands province of northeastern Washington. The band of *Pinus ponderosa* forests generally increases in elevation from north to south. Throughout much of Washington they are at approximately 600 to 1,200 meters in elevation. In the Blue Mountains province and northeastern Oregon generally, the elevational range is about 900 to 1,500 meters. Elevations in the south-central Oregon pumice area are considerably higher — about 1,450 to 2,000 meters.

At their upper limits, *Pinus ponderosa* forests may grade into forests of *Pseudotsuga menziesii, Abies grandis,* or *A. concolor* depending on the locale (table 16). Throughout much of Oregon, they abut *Artemisia tridentata* steppe or open *Juniperus occidentalis-Artemisia tridentata* woodland at their lower

Figure 94. — The *Juniperus occidentalis/Artemisia tridentata/Agropyron spicatum-Astragalus lectulus* association was the most xeric described by Driscoll (1964b).

Table 19. — Five associations found in the *Juniperus occidentalis* Zone and some characteristics of each

Association	Climax type	Coverage		
		Juniperus	Shrubs[1]	Herbs[2]
Juniperus/Artemisia/ Agropyron	Climatic	10.0	9.6	14.3
Juniperus/Festuca	Topoedaphic	76.7	1.6	15.1
Juniperus/Agropyron	Topoedaphic	43.0	1.4	9.1
Juniperus/Artemisia-Purshia	Topoedaphic	6.6	16.2	4.6
Juniperus/Artemisia/ Agropyron-Astragalus	Topoedaphic	27.7	9.8	9.6

Source: Driscoll (1964b).

[1] Shrubs and suffrutescents.
[2] Perennial herbs only.

limits. At lower elevational limits in Washington, *Pinus ponderosa* forests grade into either grassland or *Artemisia* steppe. At some locations in northern Oregon and southern Washington, there is an ecotonal belt of *Quercus garryana* between *Pinus ponderosa* forest and steppe.

The discussion of the *Pinus ponderosa* Zone which follows considers seral *Pinus ponderosa* forests as well as forests in which the *Pinus* is climax. The *Pinus ponderosa* Zone, in the strict sense, includes only the latter; in this narrower definition, the *Pinus ponderosa* Zone correlates with the Ponderosa Pine-Bunchgrass Zone of Krajina (1965) and Brayshaw (1965). It is important to realize that in many locations there is no belt of climax *Pinus ponderosa* forests between steppe and areas of *Pseudotsuga menziesii* (Brayshaw 1965; Johnson 1959) or *Abies grandis* (Hall 1967) climax. The *Pinus ponderosa* Zone, more broadly defined, correlates roughly with Merriam's Arid Transition Zone (Barrett 1962; Bailey 1936) and includes representation of Küchler's (1964) Ponderosa Shrub and Western Ponderosa Forests.

Environmental Features

The climate of the *Pinus ponderosa* Zone is characterized by a short growing season and minimal summer precipitation (table 20). Average annual precipitation ranges from about 355 to 760 millimeters, much of it falling as winter snow. Diurnal summer temperatures fluctuate widely, with hot days and cold nights. In many areas, frost may occur any night of the year. The months of July, August, and September are very dry, with rainfall averaging less than 25 millimeters. Much of this summer rain is ineffective, as it usually comes during brief, high-intensity convection storms. Winter temperatures are generally low; as a result, snow often accumulates to considerable depths.

Since *Pinus ponderosa* occupies drier sites than any other forest type (except *Juniperus occidentalis*), its distribution is closely correlated with supplies of available soil moisture. This is often reflected by a distinct relationship between occurrence of *Pinus ponderosa* and soil texture, especially at the dry end of its range. Many studies have shown better survival and growth of *Pinus ponderosa* on coarse-textured, sandy soils than on fine-textured, clayey soils (Pearson 1923; Howell 1932; Stone and Fowells 1955; Fowells and Kirk 1945). These effects can be largely attributed to more extensive root proliferation on coarse-textured soils. On xeric sites, a mosaic of *Pinus ponderosa* communities (on coarse-textured soils) and steppe or shrub-steppe communities (on finer textured soils) is common (Hall 1967). An extreme example is a disjunct stand of *Pinus ponderosa* in central Oregon, located 64 kilometers from the nearest other *Pinus ponderosa* forest (fig. 95). Despite less than 250 millimeters annual precipitation, abundant regeneration attests that the stand is maintaining itself. Berry (1963) attributed existence of this anachronistic forest primarily to the uniformly sandy soils it occupies.

Intensity of soil profile development varies with elevation and parent material. At lower elevations within the zone, soils tend to be coarse textured and generally have weakly differentiated A, B, and C horizons. Western Brown Forest is the most common zonal soil group. They have moderately dark-colored and thick A horizons grading into B horizons distinguished by color, and sometimes by structure, since clay eluviation is not characteristic. Surface soils are generally slightly acid, and reaction often becomes more neutral with depth. Soils on moister, cooler sites

Figure 95. — Coarse-textured soils favor development of *Pinus ponderosa* in forest-steppe ecotonal areas; this disjunct stand, the Lost Forest, is an extreme example, occupying sandy soils located 64 kilometers within the central Oregon shrub-steppe.

Table 20. — Climatic data from representative stations in the vicinity of the *Pinus ponderosa* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Chiloquin, Oreg.	1,280	42°35′	121°47′	6.3	−3.1	−9.4	16.3	28.4	441	43	--
Joseph, Oreg.	1,341	45°21′	117°15′	6.4	−5.3	−10.6	17.5	26.6	411	94	--
Starkey, Oreg.	1,036	45°14′	118°23′	6.3	−3.6	−10.0	16.2	28.0	457	89	--
Cle Elum, Wash.	579	47°11′	120°55′	7.4	−3.2	−7.7	18.1	27.8	537	41	219
Leavenworth, Wash.	344	47°34′	120°40′	8.4	−5.1	−9.9	20.4	30.8	590	44	252
Northport, Wash.	411	48°55′	117°47′	8.3	−4.5	−8.2	20.6	31.4	477	96	141

Source: U. S. Weather Bureau (1956, 1965a, 1965b) and Johnsgard (1963).

generally show some evidence of podzolization — e.g., they may have moderately thick accumulations of duff and litter and thin A1 horizons underlain by distinct, light-colored A2 (bleicherde) horizons. Soil reaction ranges from slight to medium acidity. The most representative great soil group is the Gray Wooded.

The *Pinus ponderosa* Zone includes large areas of immature regosolic soils, particularly the 5,000,000-hectares pumice plateau of south-central Oregon. These pumice soils are developed in deposits of dacitic and rhyolitic pumice erupted form Mount Mazama (Crater Lake) and Newberry Crater, respectively. Thin A horizons have moderate to low organic matter content and grade into relatively unweathered pumice sand and gravel. A finer textured buried soil is generally encountered at 1/2 to 3 meters. These coarse-textured pumice soils apparently enable *Pinus ponderosa* to extend its range east into areas where the vegetation would otherwise be *Artemisia* steppe. The frequent coincidence of eastern boundaries of *Pinus ponderosa* forest and pumice soil areas provides evidence for this.

Figure 96. — Groves of *Populus tremuloides* are common on riparian and poorly drained habitats within the *Pinus ponderosa* Zone (Colville Indian Reservation, Washington).

Forest Composition

Pinus ponderosa is associated with a rich variety of tree species. Only four of these — *Juniperus occidentalis*, *Populus tremuloides*, *Pinus contorta*, and *Quercus garryana* — are generally associates in climax *Pinus ponderosa* stands (the narrowly defined *Pinus ponderosa* Zone). Even these associates are restricted to specific habitats in the zone or geographically. *Juniperus occidentalis* occurs as a minor component of xeric *Pinus ponderosa* stands in much of southeastern Oregon (Dealy 1969; Swedberg 1961; West 1964). Groves of *Populus tremuloides* occur on riparian and poorly drained wet areas throughout the *Pinus ponderosa* Zone and adjacent forest and steppe zones as well (fig. 96) (Johnson 1961; Dealy 1969; Daubenmire 1952). *Quercus garryana* is associated only on the east slopes of the Cascades in northern Oregon and southern and central Washington. *Pinus contorta* and *P. ponderosa*, frequent seral associates in more mesic zones (e.g., *Pseudotsuga menziesii* Zone), are the sole constituents of extensive forests in the pumice region of south-central Oregon (Dyrness and Youngberg 1966).

The remaining tree species found in *Pinus ponderosa* stands are generally present only on sites where *Pinus ponderosa* is seral; e.g., more mesic zones such as the *Abies grandis* or *Pseudotsuga menziesii*. Any of these may occur as accidentals within climax *Pinus ponderosa* stands, however. *Abies grandis*, *Pseudotsuga menziesii*, *Larix occidentalis*, and *Pinus monticola* are associated with *Pinus ponderosa* essentially throughout northeastern Oregon and eastern Washington (including eastern slopes of the Cascade Range) (Swedberg 1961; Hall 1967; Daubenmire and Daubenmire 1968). *Libocedrus decurrens* occurs only along the eastern slopes of the central and northern Oregon Cascades (Swedberg 1961; West 1969; Sherman 1969). *Abies concolor* is a major constituent of some seral *Pinus pon-*

Figure 97. — The open nature of many mature *Pinus ponderosa* stands provides niches for sciophytic species, including many typical of steppe and shrub-steppe communities (eastern slopes of the Cascade Range near Sisters, Oregon).

derosa stands of the southern and central Oregon Cascade Range and pumice region (Volland 1963; Dyrness and Youngberg 1966).

Community composition in *Pinus ponderosa* stands varies widely with geographic location, soils, elevation and aspect, and successional status. The history of stand disturbances, such as by fire and logging, influence overstory density which, in turn, can have profound effects on understory composition and density (Moir 1966; Robinson 1967; Sherman 1966). The open nature of typical mature *Pinus ponderosa* stands (fig. 97) provides abundant niches for sciophytic species, including many typical of steppe and shrub-steppe communities.

Pinus ponderosa community types or associations have been identified in many localities: (1) south-central Oregon (Volland 1963; Dyrness 1960; Dyrness and Youngberg 1966; Dealy 1969), (2) the Blue Mountains of northeastern Oregon,[17] and (3) eastern Washington (Daubenmire 1952; Daubenmire and Daubenmire 1968). West (1964) and Swedberg (1961) found a continuum viewpoint useful in interpreting *Pinus ponderosa* communities along environmental gradients on the eastern slopes of Oregon's Cascade Range. All of these studies show that some characteristic understory dominants, such as *Festuca idahoensis* and *Purshia tridentata*, occur throughout the entire zone — from northeastern Washington to south-central Oregon. However, many others have more restricted distributions, so that the character of the understory tends to vary with locale. Consequently, communities will be considered by geographic location.

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[17] F. C. Hall (1967) and personal communications.

Figure 98. — Grassy *Pinus ponderosa* communities often consist of a mosaic of arborescent and herbaceous patches, the latter developing well only in treeless openings; a *Pinus ponderosa/Agropyron spicatum* community in eastern Oregon.

In eastern Washington, six *Pinus ponderosa* associations have been recognized (Daubenmire and Daubenmire 1968):

Pinus ponderosa/Symphoricarpos albus,
Pinus ponderosa/Physocarpus malvaceus,
Pinus ponderosa/Festuca idahoensis,
Pinus ponderosa/Agropyron spicatum,
Pinus ponderosa/Stipa comata, and
Pinus ponderosa/Purshia tridentata.

The first two associations comprise a shrubby group found on deep, fine-textured, fertile soils. *Pinus* reproduction is sparse, but sufficient to produce an all-aged forest. The *Pinus ponderosa/Symphoricarpos albus* association is considered a climatic climax (Daubenmire 1952), since it occurs on loamy soils and undulating topography. The understory is dominated by a nearly continuous, 0.5- to 1-meter-tall cover of low, deciduous shrubs, mainly *Symphoricarpos albus*, *Spiraea betulifolia* var. *lucida*, *Rosa woodsii*, and *R. nutkana*. There is a rich variety of herbaceous, mainly perennial, associates, of which several grasses (e.g., *Calamagrostis rubescens*, rhizomatous *Agropyron spicatum*) have the highest constancies. The *Pinus ponderosa/Physocarpus malvaceus* association occupies slightly more mesic sites and adds a taller shrub layer (2 m.) of *Physocarpus malvaceus*, *Holodiscus discolor*, and *Ceanothus sanguineus* to the *Symphoricarpos* understory discussed above.

The other four *Pinus ponderosa* associations — *Festuca idahoensis*, *Agropyron spicatum*, *Stipa comata*, and *Purshia tridentata* — Daubenmire and Daubenmire (1968) refer to as a grassy group (fig. 98). Understories are dominated by xerophytic grasses; soils are stony, coarse textured, or shallow; and reproduction of *Pinus* is episodic. The first three associations were grouped in a *Pinus ponderosa/Agropyron spicatum* association in an earlier study (Daubenmire 1952). Each has an understory dominated almost exclusively by a single large perennial bunchgrass — *Festuca*

idahoensis, caespitose *Agropyron spicatum*, or *Stipa comata*. The *Pinus ponderosa/Purshia tridentata* association has a *Purshia*-dominated shrub layer superimposed on a variety of perennial grasses including *Festuca idahoensis*, caespitose *Agropyron spicatum*, *Stipa comata*, and *Aristida longiseta*. In some stands, forbs such as *Balsamorhiza sagittata* and *Erigeron compositus* are abundant.

Cooke (1955) has provided data on occurrence of fungi, mosses, and lichens in *Pinus ponderosa/Agropyron spicatum* and *Pinus ponderosa/Symphoricarpos albus* stands in eastern Washington and adjacent Idaho.

Studies have indicated that soil moisture regime is the most important single factor influencing the distribution of these climax vegetation types (McMinn 1952; Daubenmire 1968b). Supplies of available soil moisture are exhausted early in the growing season in areas of the more xeric habitat types; e.g., *Pinus ponderosa/Agropyron spicatum*. Mesic associations are characterized by a delayed onset of soil drought.

Six climax *Pinus ponderosa* associations have been identified in the Blue Mountains province.[18] The *Pinus ponderosa/Agropyron spicatum* and *Pinus ponderosa/Purshia tridentata/Agropyron spicatum* associations are often found in areas transitional between steppe or shrub-steppe and forest. In the extreme southern Blue Mountains, a *Pinus ponderosa/Purshia tridentata/Carex rossii* association is found on some coarse-textured soils. *Sitanion hystrix* and *Stipa occidentalis* are common associates in the herb-poor understory. *Pinus ponderosa/Elymus glaucus* communities are limited to areas adjacent to dry meadows. The *Pinus ponderosa/Festuca idahoensis* associations are characterized by an abundance of other grasses and sedges in the understory, including *Agropyron spicatum*, *Sitanion hystrix*, *Calamagrostis rubescens*, *Carex rossii*, and *C. geyeri*. At higher elevations, adjacent to *Abies grandis* forests, the *Pinus ponderosa/Carex geyeri* association occurs. Constituent species include *Cercocarpus ledifolius* and *Poa nervosa*.

Apparently, many *Pinus ponderosa* stands on the eastern slopes of Washington's Cascade Range (Rummell 1951; Weaver 1961) and in the Blue Mountains (Hall 1967) have an understory dominated by *Calamagrostis rubescens* or mixed *Calamagrostis* and *Carex geyeri*. Hall[19] identified two communities of this type in the Blue Mountains, one with herbaceous associates (e.g., *Arnica cordifolia*, *Hieracium albiflorum*, and *Carex concinnoides*), the other with herbs and a shrubby layer of *Symphoricarpos albus*, *Spiraea*, and *Rosa*. However, *Pinus ponderosa* is seral to *Pseudotsuga menziesii* or *Abies grandis* in these Blue Mountains communities and, perhaps, in most *Pinus/Calamagrostis* communities in the Washington Cascades as well.

Understory vegetation found in *Pinus ponderosa* stands on pumice soils in south-central Oregon differs considerably from that found on nearby residual soils. Total plant cover tends to be lower, especially in the more xeric communities, and the herbaceous flora is more depauperate on pumice soils. Sclerophyllous shrubs such as *Arctostaphylos patula*[20] and *Ceanothus velutinus* assume much more importance in these areas (fig. 99).

Communities occurring on pumice soils, in order of increasing effective moisture, are (Dyrness and Youngberg 1966):

Pinus ponderosa/Purshia tridentata,
Pinus ponderosa/Purshia tridentata/Festuca idahoensis,
Pinus ponderosa/Purshia tridentata-Arctostaphylos patula,
Pinus ponderosa/Ceanothus velutinus-Purshia tridentata, and
Pinus ponderosa/Ceanothus velutinus.

With the exception of the seral *Pinus/Ceanothus*, these communities are considered to be

[18] F. C. Hall (1967) and personal communication.

[19] F. C. Hall, personal communication.

[20] This taxon has been variously identified as *Arctostaphylos patula* Greene, *A. parryana* var. *pinetorum* (Rollins) Wiesl. & Schr., *A. patula* ssp. *Platphylla* (Gray) P. V. Wells, and *A. obtusifolia* Piper. These revisions were made to distinguish the nonsprouting types prevalent in eastern Oregon from the crown-sprouting *Arctostaphylos patula*. For convenience, we will refer to this entire group as *Arctostaphylos patula* Greene.

Figure 99. — Sclerophyllous shrubs such as *Ceanothus velutinus* are important understory species in *Pinus ponderosa* stands on pumice soils in south-central Oregon; a *Pinus ponderosa/Ceanothus velutinus* community.

Figure 100. — *Pinus ponderosa/Purshia tridentata* communities in the central Oregon pumice region are characterized by open stands with little *Pinus* regeneration.

edaphic climaxes because of the immaturity of the pumice soils. The *Pinus/Purshia* community is situated at lowest elevations and is characterized by open stands having little advance pine regeneration (fig. 100). Grass and herbaceous cover is sparse; characteristic species are *Stipa occidentalis*, *Sitanion hystrix*, *Gayophytum diffusum*, and *Cryptantha affinis*. The *Pinus/Purshia/Festuca* community occurs on finer textured soils derived from water-lain pumice deposits. Numerous dense stands of *Pinus ponderosa* seedlings and saplings are present in the understory. Characteristic species include *Stipa occidentalis*, *Carex rossii*, *Achillea millefolium* var. *lanulosa*, *Paeonia brownii*, and *Eriophyllum lanatum*.

The *Pinus/Purshia-Arctostaphylos* community is situated at slightly higher elevations than the *Pinus/Purshia* and is accompanied by greater amounts of tree reproduction and seral *Pinus contorta*. This community shares many species with the *Pinus/Purshia*, but has additional herbs such as *Phacelia heterophylla*, *Fragaria cuneifolia*, and *Epilobium angustifolium*. In the *Pinus/Ceanothus-Purshia* community, *Ceanothus velutinus* replaces *Arctostaphylos patula* in the shrub layer. More abundant tree reproduction and occasional patches of *Salix* sp. indicate more mesic conditions. Characteristic grasses and herbs are *Stipa occidentalis*, *Carex rossii*, *Sitanion hystrix*, *Apocynum androsaemifolium*, and *Hieracium cynoglossoides*. In the *Pinus/Ceanothus* community *Abies concolor* generally dominates the tree reproduction (fig. 99) and is, therefore, assumed to be climax (Volland 1963; Dyrness and Youngberg 1966). The *Pinus/Ceanothus* type is restricted to higher elevations, and characteristic species include *Chimaphila umbellata* and *Pyrola picta*.

On residual soils in south-central Oregon, *Festuca idahoensis* is much more widespread, generally dominating the herbaceous layer under *Pinus ponderosa* stands (Dealy 1969). Apparently, the climatic climax in this area is represented by the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* association. On residual soils, this association is characterized by herbaceous species such as *Balsamorhiza sagittata* and *Hieracium cynoglossoides*, which are absent in pumice soil areas.

Successional Patterns

The importance of fire in shaping the vegetation within the *Pinus ponderosa* Zone is stressed by virtually every ecologist who worked there. Fire scars at the base of almost every large tree offer abundant evidence of repeated fires. Before fire control was initiated about 1900, fires burned through *Pinus ponderosa* stands at intervals variously reported as 8 to 20 years (Weaver 1955, 1959; Soeriaatmadja 1966; Hall 1967). Generally, these were ground fires which consumed only surface organic debris, including branches and down trees, a portion of the understory vegetation, and many of the young tree seedlings.

Because *Pinus ponderosa* is more fire resistant than most associated tree species, past fires have had a profound effect on its distribution. Although young *Pinus ponderosa* seedlings are readily killed by fire, older trees possess thick bark which offers effective protection from fire damage. Competing tree species, such as *Abies grandis* and *Pseudotsuga menziesii*, are considerably less fire tolerant, especially in the sapling and pole size classes. As a result, periodic fires in the past served to maintain *Pinus ponderosa* in ecotonal areas where, without fire disturbance, the climax tree species would have attained dominance (Weaver 1955, 1959, 1961). Fire control activities during the past 60 to 70 years have, on the moister sites, resulted in gradual replacement of *Pinus ponderosa* by such species as *Abies concolor*, *A. grandis*, *Libocedrus decurrens*, and *Pseudotsuga menziesii* (Swedberg 1961; Johnson 1961; West 1969).

Fire has also influenced the understory vegetation. Several workers reported that burning substantially reduces shrub cover and increases grass cover, especially on more xeric sites (Brayshaw 1965; Hall 1967; Daubenmire and Daubenmire 1968). *Purshia tridentata* is probably most readily eliminated of the common shrubs, although on some sites fire reduction and consequent competition from increases in canopy density may have the same effect (Sherman 1966). On the other hand, the shrubs *Arctostaphylos patula* and *Ceanothus velutinus* may increase in importance following severe fires (fig. 101) since heat gener-

Figure 101. — Fires in *Pinus ponderosa* forests on the east slope of Oregon's Cascade Range may give rise to communities dominated by sclerophyllous shrubs such as *Arctostaphylos patula* and *Ceanothus velutinus.*

Figure 102. — Dense, stagnated thickets of *Pinus ponderosa* saplings are common on shallow, stony soils in the *Pinus ponderosa* Zone; these are frequently attributed to the exclusion of periodic, natural wildfires during the last 50 years.

ated by burning aids in germination of seeds of these species (Gratkowski 1962; Johnson 1961). In the absence of fire, these species apparently perpetuate themselves, at least in pumice soil areas, by vegetative regeneration (Dyrness 1960).

Dense, stagnated stands of *Pinus ponderosa* saplings are common throughout the zone (fig. 102), especially on shallow, stony soils of low productivity. These stands have been attributed to fire exclusion during the past half century (Weaver 1955, 1959, 1961). It is claimed that, previously, periodic fires regulated amounts of advance regeneration and resulted in the open, grassy, parklike stands that early settlers described. However, Daubenmire and Daubenmire (1968) feel that the dense, patchy, episodic reproduction in their grassy *Pinus ponderosa* associations cannot be completely attributed to fire control since a patchy structure is absent in *Pinus/Symphoricarpos* and *Pinus/Physocarpus* stands. Furthermore, it is possible that many *Pinus ponderosa* thickets actually originated with fires. Brayshaw (1965) observed that burning immediately preceding a heavy seed year assisted establishment of unusually numerous pine seedlings by greatly reducing competition from other vegetation. West (1968) reported that at least 15 percent of *Pinus ponderosa* seedlings develop from unrecovered rodent caches in central Oregon (fig. 103).

In many areas, there is a strong tendency for climax *Pinus ponderosa* forests to be even aged by small groups rather than to be truly uneven aged. Daubenmire and Daubenmire (1968) commented that grassy *Pinus ponderosa* stands consist of "... a mosaic of dense patches of trees, each tending to be distinctive in height and age."

Heavy livestock grazing has, in some respects, effects on understory vegetation opposite to those of burning. That is, heavy grazing pressures often favor shrubs at the expense of grass cover. For example, Brayshaw (1965) reports that heavy grazing may extend the *Symphoricarpos* type into areas formerly dominated by *Agropyron.* On the other hand, grazing in *Pinus/Symphoricarpos* stands may eliminate all native shrubs and herbs, resulting in a sward of *Poa pratensis* and *P. compressa* (Daubenmire and Daubenmire 1968). Changes

Figure 103. — *Pinus ponderosa* seedlings often develop from unrecovered seed caches of rodents in the Oregon Cascade Range.

in grass species may also occur as a result of grazing pressure. Understories in the *Pinus ponderosa/Festuca idahoensis* association in northeastern Washington can be shifted, apparently irreversibly, to domination by *Bromus tectorum*, *Linaria dalmatica*, and *Hypericum perforatum* (Daubenmire and Daubenmire 1968).

Logging in the *Pinus ponderosa* Zone is usually carried out on a single-tree selection basis. Most often, older trees, which are more susceptible to attack by the western pine beetle (*Dendroctonus brevicomis*) are removed first, leaving the younger, more vigorous trees in the stand as growing stock (fig. 104). Selective logging of *Pinus ponderosa* in areas transitional to *Abies grandis* or *A. concolor* substantially accelerates the successional trend towards dominance by these climax tree species. Some forest managers attempt to reserve these sites for the growth of *Pinus ponderosa* through the removal of *Abies* seed sources wherever practical (Volland 1963).

Logging also affects the understory vegetation and reproduction of *Pinus ponderosa.* In one study (Garrison and Rummell 1951; Garrison 1961, 1965), selective logging by tractors reduced herb and shrub coverage by 33 percent, denuding some areas and burying others in slash. The understory required about 14 years to recover to near its original condition. Deforestation generally results in dominance by those understory species present before logging, with invading species playing only a very minor role in the postdisturbance period (Daubenmire 1952); a notable exception is *Crataegus douglasii* on *Pinus/Symphoricarpos* sites (Daubenmire and Daubenmire 1968).

Figure 104. — Logging in the *Pinus ponderosa* Zone is usually carried out on a selective basis to eliminate overmature, low-vigor trees (of which several are visible here) susceptible to attack by the western pine beetle (Pringle Falls Research Natural Area, Deschutes National Forest, Oregon).

Figure 105. — *Pinus ponderosa* **forest and steppe or shrub-steppe often form an intricate mosaic in ecotonal areas with the communities on coarser and finer textured soils, respectively (near Tonasket, Okanogan National Forest, Washington).**

Nonforested Communities

Pinus ponderosa forests form a mosaic with shrub-steppe or steppe communities in many locales (fig. 105). For example, in eastern Washington, *Pinus ponderosa* stands first appear within a matrix of steppe, and increase in extent in more mesic areas until steppe or shrub-steppe communities constitute islands within a matrix of *Pinus ponderosa* forest (Daubenmire and Daubenmire 1968). Many of the nonforest communities in the *Pinus ponderosa* Zone are identical with those found within the steppe zones, e.g., the *Purshia tridentata/Festuca idahoensis* association (Daubenmire 1969); others occur only in forest zones.

One of the best described *Pinus ponderosa*-steppe mosaics is that encountered in the Ochoco Mountains of eastern Oregon (Hall 1967). Hall described three associations which occur in natural forest openings:

Artemisia rigida/Poa secunda with *Sitanion hystrix* and *Trifolium macrocephalum* as major associates;

Artemisia arbuscula/Agropyron spicatum with *Poa secunda* and *Purshia tridentata* as major associates; and

Artemisia arbuscula/Festuca idahoensis with *Phlox douglasii, Balsamorhiza serrata,* and *Poa secunda* as associates.

Hall (1967) attributed the presence of these nonforested communities to soil conditions, specifically to periodic moisture saturation, heavy soils which impede tree root penetration, and soil drought during the summer. He also mentioned a *Purshia tridentata-Cercocarpus ledifolius*-dominated community, characteristic of rock outcrops in the lower part of the *Pinus ponderosa* Zone.

Daubenmire (1969) mentioned two communities, encountered as edaphic climaxes within the forested zones of eastern Washington. The *Artemisia rigida/Poa secunda* association is widely distributed on Lithosols from steppe through the *Pseudotsuga menziesii* Zone. The *Festuca idahoensis-Eriogonum heracleoides* association is found only in forest "parks" and includes *Antennaria rosea* and *Castilleja miniata* as characteristic species.

Severe fires or destructive logging practices can eliminate *Pinus ponderosa* and give rise to shrub-dominated communities, as mentioned earlier. Reestablishment of trees in such communities may be very slow.

"PINUS CONTORTA" ZONE

Pure, or nearly pure, stands of *Pinus contorta* are widely distributed throughout forested areas of eastern Oregon and Washington. The majority are seral, having developed after fire or logging. However, *Pinus contorta* is considered an edaphic or topoedaphic climax on many sites in the pumice plateau of south-central Oregon. Since other areas where *Pinus contorta* may be a climax tree species are small and very scattered, our *Pinus contorta* Zone will be limited to the pumice plateau. It is interesting that Moir (1969) has recently provided experimental evidence for a *Pinus contorta* Zone in the Rocky Mountains.

Pinus contorta is well known for rapid invasion of severely disturbed sites, justifying its designation as a pioneer species. Pollen analyses indicate it was one of the first trees to occupy the infertile materials deposited at the close of the last glacial period in the southern Oregon Cascades (Hansen 1946). After gradual replacement by *Pinus ponderosa* during the succeeding 25 centuries, *Pinus contorta* quickly regained dominance with the widespread deposition of Mount Mazama pumice 6,600 years ago. It has retained dominance on pumice and ash soils at several other locations in the Oregon and Central Washington Cascades (Roach 1952; Herring 1968). *Pinus contorta* forests are extensive on volcanic ash and pumice in the Blue Mountains of northeastern Oregon (Trappe and Harris 1958), but are rarely found on south slopes where this material is thin or absent. These forests are apparently fire created and generally seral to *Abies grandis*.

Pinus contorta has unusually wide ecologic amplitude — thriving on wet, poorly drained sites, as well as coarse-textured, droughty soils. After fires, prolific seeding allows it to quickly invade and establish dominance, especially on more extreme sites where competitors are absent. For this reason, pure stands of *Pinus contorta* are often found only on very wet or dry soils, and the more productive, medium-textured soils support other tree species (Stephens 1966).

Environmental Features

The climate of the *Pinus contorta* Zone is characterized by (1) low summer rainfall, (2) wide diurnal temperature fluctuations, especially in the summer, and (3) a relatively short growing season (table 21). Since elevations within the zone range from approximately 1,200 to 1,525 meters, growing-season frosts are not uncommon, and much of the precipitation occurs as snow. Average annual precipitation ranges from about 350 to 700 millimeters.

Topographically, the pumice plateau includes broad, level areas in enclosed depressions, gently rolling terrain, and numerous small volcanic cones. *Pinus contorta* stands are generally on nearly level terrain in depressions locally known as lodgepole flats. Temperature measurements show that cold-air drainage from surrounding slopes often produces substantially lower nighttime temperatures in these low-lying areas. For example, Berntsen (1967) found minimum spring temperatures were as much as 4.5° C. higher on a slope supporting *Pinus ponderosa* than those registered in an adjacent *Pinus contorta* stand at the base of the slope.

Climax stands of *Pinus contorta* are found on both well and poorly drained pumice soils. All are Regosols developed in aerially deposited pumice, mostly from Mount Mazama (Crater Lake). Poorly drained soils occupy low topography in basinlike depressions or areas adjacent to intermittent streams. These soils have a dark-gray sandy loam or loam A1 horizon underlain by a light-gray to white C horizon composed of pumice gravel and sand. Depth to water table is generally 60 centimeters or less throughout the growing season. On better drained sites, the pumice soil exhibits (1) a thin, dark grayish-brown, loamy coarse sand A1 horizon underlain by (2) a yellowish-brown, gravelly, loamy coarse sand AC horizon which grades, in turn, into (3) relatively fresh, unweathered pumice gravel and sand (fig. 106).

Table 21. — Climatic data from representative stations within the *Pinus contorta* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Chemult, Oreg.	1,449	43°14′	121°47′	5.3	−3.9	−11.1	15.3	28.2	676	66	417
Crescent, Oreg.	1,357	43°27′	121°42′	5.1	−3.1	−11.2	14.3	26.8	485	56	---
Lapine, Oreg.	1,336	43°40′	121°29′	5.6	−3.3	−10.8	15.5	29.8	361	64	---

Source: U. S. Weather Bureau (1965a) and Johnsgard (1963).

Forest Composition

Four communities have been identified in the *Pinus contorta* Zone (Youngberg and Dahms 1969):

Pinus contorta/Arctostaphylos uva-ursi,
Pinus contorta/ Purshia tridentata/ Festuca idahoensis,
Pinus contorta/Purshia tridentata, and
Pinus contorta/Purshia tridentata-Ribes cereum.

The *Pinus/Arctostaphylos* community grows on poorly drained soils and is rich in grasses and herbs. Characteristic species include *Ribes cereum*, *Fragaria cuneifolia*, *Trifolium longipes*, and *Festuca idahoensis*. The *Pinus/Purshia/Festuca* community occurs on seasonally wet soils and includes such species as *Ribes cereum*, *Fragaria cuneifolia*, *Sitanion hystrix*, and *Carex rossii*. Both *Pinus/Purshia* (fig. 107) and *Pinus/Purshia-Ribes* communities appear on well-drained sites where *Pinus contorta* is climax because of low temperatures. Understory cover in the *Pinus/Purshia* type is sparse with characteristic species (e.g., *Stipa occidentalis*, *Sitanion hystrix*, and *Carex rossii*) similar to those occurring in nearby *Pinus ponderosa/Purshia tridentata* stands.

Figure 106. — Better drained pumice soils in south-central Oregon typically have dark-colored A1 and AC horizons overlying the lighter colored gravelly C; note the abrupt boundary between Mazama pumice and buried soil.

Figure 107. — The *Pinus contorta/Purshia tridentata* community is widespread in the central Oregon pumice region; *Pinus contorta* achieves climax status on poorly drained sites and in frosty depressions in this area (Pringle Falls Research Natural Area, Deschutes National Forest, Oregon).

Figure 108. — *Pinus contorta* **regeneration is often excessive on disturbed sites or in decadent stands, resulting in dense, stagnated patches of saplings.**

Species composition of the *Pinus/Purshia-Ribes* community is similar to that of the *Pinus/Purshia* except for the addition of *Ribes cereum* and *Fragaria cuneifolia.*

Successional Patterns

Kerr (1913) first reported the interesting forest patterns in this area. Pure stands of *Pinus contorta* occupy depressions and broad, level areas at lower elevations, but on every hill and slight rise in topography it is replaced by *Pinus ponderosa.* Munger (1914) concluded that *Pinus contorta* owed its widespread distribution to frequent fires and contended that it was continually encroaching on sites previously occupied by *Pinus ponderosa.* Later, however, the effects of fire were discounted when soil investigations disclosed that many sites supporting pure stands of *Pinus contorta* were subject to permanent or fluctuating high water tables (Tarrant 1953). Further study of the area revealed many sites where climax stands of *Pinus contorta* were growing on well-drained soils. Since these were generally located in enclosed depressions suggestive of frost pockets, it was postulated that *Pinus contorta* occupied these sites because of its greater resistance to low temperatures, especially during the early growing season (Youngberg and Dyrness 1959). Berntsen (1967) confirmed this hypothesis and indicated selection for *Pinus contorta* occurs during seed germination. Emerging *Pinus contorta* seedlings were appreciably more resistant to low temperatures than *Pinus ponderosa* seedlings.

Consequently, two types of climax *Pinus contorta* stands have been recognized: (1) an edaphic climax in poorly drained soil areas, and (2) a topoedaphic climax in frost pocket depressions where the soil is often well drained. The transition between nearly pure stands of *Pinus contorta* and those of *Pinus ponderosa* on adjacent slopes is often strikingly abrupt, although there frequently is a narrow band where the two species intermingle. Climax *Pinus contorta* stands are generally even aged and nearly pure, except for occasional clumps of *Populus tremuloides* in poorly drained areas. As stands reach old age and

begin to break up, they are quickly replaced by abundant *Pinus contorta* seedlings (fig. 108). Cones in these populations are nonserotinous; therefore, seed fall occurs virtually every year (Mowat 1960).

Nonforested Communities

Numerous wet meadows are interspersed with *Pinus contorta* stands at lowest elevations within the zone (fig. 109). These meadows are on very poorly drained pumice soils and exhibit a mesic flora as a result of the shallow water table. Principal grasses are *Poa* spp., *Deschampsia caespitosa*, and *Sitanion hystrix*. In addition, *Juncus* spp. and sedges such as *Carex praegracilis* and *Carex nebraskensis* are common. Herbaceous species vary appreciably depending on grazing pressure; however, two of the more common are *Trifolium longipes* and *Ranunculus occidentalis* (Dyrness 1960).

"PSEUDOTSUGA MENZIESII" ZONE

Associations in which *Pseudotsuga menziesii* is climax are the next zonal step in some areas. In most of eastern Washington and adjacent British Columbia, a *Pseudotsuga menziesii* Zone is apparently well developed (Daubenmire 1952, 1966; Daubenmire and Daubenmire 1968; Brayshaw 1965). In eastern Oregon, it is conjectural (West 1964, 1969; Swedberg 1961) or absent (Dyrness and Youngberg 1966; Hall 1967), except in parts of the Wallowa Mountains (Johnson 1959; Head 1959). A typical elevational range for the zone is 600 to 1,300 meters in northeastern Washington. The *Pseudotsuga menziesii* Zone correlates with the Interior Douglas-fir Zone in British Columbia (Krajina 1965) and the lower part of the Canadian Life Zone (Barrett 1962).

The *Pseudotsuga menziesii* Zone normally abuts the *Abies grandis* and *Pinus ponderosa* Zones at its upper and lower limits, respectively (table 16). In places, climax *Pinus ponderosa* forests may be absent and the *Pseudotsuga menziesii* Zone borders shrub steppe; this is particularly common on fine-textured soils in north-central Washington. In other locations, *Abies grandis* forests are absent and *Abies lasiocarpa* abuts the upper limits of the *Pseudotsuga menziesii* Zone.

Environmental Features

The *Pseudotsuga menziesii* Zone is more mesic than the *Pinus ponderosa* Zone. Temperatures undoubtedly average cooler and annual precipitation higher (Krajina 1965), although Daubenmire (1956) could not identify climatic criteria distinguishing the zones at their ecotone. It is known that soil moisture conditions are more favorable in the *Pseudotsuga menziesii* Zone (Daubenmire 1968b; McMinn 1952; Brayshaw 1965).

Forest Composition

Pseudotsuga menziesii, *Pinus ponderosa*, *P. contorta*, and *Larix occidentalis* are the major tree species in the *Pseudotsuga menziesii* Zone (fig. 110). *Quercus garryana* may be present along the flanks of the Cascade Range from about 45° to 47° north latitude. *Libocedrus decurrens* also occurs from Mount Hood south. *Populus tremuloides* and *Juniperus occidentalis* are minor associates.

Pseudotsuga menziesii associations have been identified only in eastern Washington and the Wallowa Mountains (Daubenmire

Figure 109. — Numerous wet meadows dominated by grasses and sedges are interspersed with *Pinus contorta* stands at lower elevations in the *Pinus contorta* Zone (Bear Flat between Chemult and Silver Lake, Oregon).

Figure 110. — Mixed stands of *Pseudotsuga menziesii* and *Larix occidentalis* are common in parts of the *Pseudotsuga menziesii* Zone; note reproduction of the climax *Pseudotsuga* (Colville National Forest, Washington).

Figure 111. — *Pseudotsuga menziesii* replacing *Pinus ponderosa* (Meeks Table Research Natural Area, Snoqualmie National Forest, Washington).

1952; Daubenmire and Daubenmire 1968; Johnson 1959; Head 1959). Daubenmire recognized two associations with shrubby understories in his study area. The *Pseudotsuga menziesii/Symphoricarpos albus* association has an understory dominated by low shrubs: *Symphoricarpos albus*, *Spiraea betulifolia*, var. *lucida*, *Rosa woodsii*, and *R. nutkana*. Taller shrubs belonging to the *Physocarpus* union (Daubenmire 1952) are absent. Similar communities were noted by Johnson (1959). The *Pseudotsuga menziesii/Physocarpus malvaceus* association includes the aforementioned shrubs as understory constituents and *Physocarpus malvaceus* and *Holodiscus discolor*.

The *Pseudotsuga menziesii/Calamagrostis rubescens* association is probably the most widespread, existing in the Wallowa Mountains (Head 1959) as well as in eastern Washington (Daubenmire and Daubenmire 1968). It has a nearly shrub-free understory, dominated by *Calamagrostis rubescens* along with other herbs such as *Carex concinnoides*, *C. geyeri*, and *Arnica latifolia*. Daubenmire and Daubenmire (1968) have recognized a phase of this type in which *Arctostaphylos uva-ursi* is an understory dominant. Similar forest communities occur in adjacent British Columbia (Brayshaw 1965).

Successional Patterns

Any of the four major tree species — *Pseudotsuga menziesii*, *Pinus ponderosa*, *P. contorta*, and *Larix occidentalis*— may dominate forest stands in the *Pseudotsuga menziesii* Zone. *Pseudotsuga menziesii* is climax (fig. 111), but the other three are better adapted to fires, which were common prior to 1900. Hence, any of these species may form pure or nearly pure stands, depending upon fire history and available seed source. This is one of the zones in which fire protection and selective logging of *Pinus ponderosa* are accelerating natural trends toward elimination of the pine.

As mentioned, a zone of climax *Pseudotsuga menziesii* forest is largely conjectural on the eastern slopes of the central Oregon Cascade Range. There are *Pinus ponderosa* forests with *Pseudotsuga menziesii* and *Libocedrus decurrens* reproduction (West 1964, 1969;

Swedberg 1961; Sherman 1969) suggesting either one or both are climax. However, at least small numbers of *Abies grandis* seedlings are normally present whenever significant numbers of *Pseudotsuga* are encountered. The question thus remains whether habitats with potential climax communities of *Pseudotsuga menziesii* exist in this area or whether the zonal sequence is *Pinus ponderosa-Abies grandis*. A better case can be made for climax *Libocedrus decurrens* habitats in at least some areas [see West's (1964, 1969) Warm Springs transect and Sherman (1969)]. *Libocedrus* appears tolerant of more xeric habitats than *Pseudotsuga menziesii* and is more shade tolerant than *Pinus ponderosa*.

The *Pseudotsuga menziesii* Zone definitely seems to be absent in south-central Oregon and the Ochoco and Blue Mountains (Hall 1967). Hall recognized no association in which *Pseudotsuga menziesii* was a major climax dominant.

"ABIES GRANDIS" ZONE

The *Abies grandis* Zone is the most extensive midslope forest zone in the Oregon and southern Washington Cascade Range and Blue Mountains of eastern Oregon. The *Abies grandis* Zone typically occurs at 1,100 to 1,500 meters in the central Oregon Cascade Range, 1,500 to 2,000 meters in the Ochoco and Blue Mountains (Hall 1967), and 1,650 to 2,000 meters (*Abies concolor* Zone) in south-central Oregon (Dyrness and Youngberg 1966). The *Abies grandis* Zone has no counterpart in British Columbia, and climax *Abies grandis* forests are included in the *Tsuga heterophylla* series in the northern Rocky Mountains (Daubenmire and Daubenmire 1968). This zone is analagous to the upper part of Merriam's Canadian Life Zone (Barrett 1962) and the forests within Küchler's (1964) Grand Fir-Douglas-Fir type.

The *Abies grandis* Zone is typically bounded by the *Abies lasiocarpa* Zone at its upper limits and the *Pseudotsuga menziesii* or *Pinus ponderosa* Zones at its lower limits. However, locally at higher elevations or on more mesic sites in the Cascade Range, it may abut forests in which *Abies amabilis*, *Tsuga heterophylla*, *Thuja plicata*, or *Tsuga mertensiana* are climax. At its lower limits, it may be adjacent to *Artemisia* steppe without an intervening belt of climax *Pseudotsuga menziesii* or *Pinus ponderosa* (Hall 1967).

Environmental Features

The *Abies grandis* Zone provides the most moderate environmental regime of any of the east-side forest zones (except for the areas where *Tsuga* or *Thuja* are present) (table 22). Neither moisture nor temperature conditions are extreme. Precipitation is generally higher and temperatures lower than in lower forested zones. Daubenmire (1956, 1968b) concluded that differences in summer dryness and soil drouth differentiate the *Abies grandis* and *Tsuga heterophylla* from the *Pseudotsuga menziesii* associations. Soil drouth is of minor ecologic significance in the *Abies grandis* Zone (Daubenmire 1968b, McMinn 1952). The *Abies grandis* Zone is distinguished climatically from subalpine forests by its higher temperatures (Daubenmire 1956) and lesser accumulations of snow.

Soils generally exhibit minimal development in the *Abies grandis* Zone but are relatively deep largely due to accumulations of volcanic ash throughout much of the zone's range. The dominant soil processes are podzolic, and typical great soil groups are Gray Wooded, Brown Podzolic, and Western Brown Forest. Regosolic soils with A-C profile sequences in pumice or ash parent materials are also common. Thin (2 to 5 cm.), mull-type humus layers are typical along with relatively thin, brown or dark-brown, weakly to moderately acid A1 horizons. Continuous bleached A2 horizons (bleicherde) are not common. Clay eluviation is minimal in B horizons which are distinguished primarily by color. *Abies concolor* sites in the pumice region are distinguished by A1-AC-C sequences. A horizons average only 30 centimeters thick; they are generally slightly acid (pH 6.2) with 8 to 9 percent of organic matter.

Forest Composition

Major tree species in the *Abies grandis* Zone are *Abies grandis* (or *A. concolor*), *Pinus*

Table 22. — Climatic data from representative stations in the vicinity of the *Abies grandis* Zone

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Parkdale, Oreg.	530	45°31′	121°36′	8.4	−1.3	5.1	17.6	26.9	1,064	43	231
Meacham, Oreg.	1,234	45°30′	118°24′	6.4	−3.6	−7.1	17.6	25.4	835	115	396
Minam, Oreg.	1,092	45°41′	117°36′	--	--	--	--	--	632	82	--
Mount Adams Ranger Station, Wash.	597	46°00′	121°32′	8.1	−2.1	−6.1	18.4	28.6	1,157	44	309
Lake Wenatchee, Wash.	600	47°50′	120°48′	--	--	--	--	--	988	51	450
Plain, Wash.	549	47°46′	120°40′	7.2	−4.6	−9.7	18.3	28.2	632	43	--

Source: U. S. Weather Bureau (1965a, b).

ponderosa, *P. contorta*, *Larix occidentalis*, and *Pseudotsuga menziesii*. Any of the four associates listed here may dominate seral forest stands. Many other species are present in limited numbers or in localized areas such as *Picea engelmannii*, *Abies lasiocarpa*, *Libocedrus decurrens*, *Pinus lambertiana*, *P. monticola*, *Tsuga mertensiana*, and *Abies magnifica* var. *shastensis*.

Composition of *Abies grandis* (or *A. concolor*) associations has been studied in eastern Washington (Daubenmire 1952; Daubenmire and Daubenmire 1968), the central Oregon Cascade Range (Swedberg 1961; Sherman 1969; West 1964), the Ochoco and Blue Mountains (Hall 1967), the Wallowa Mountains (Johnson 1959; Head 1959), and south-central Oregon (Dyrness and Youngberg 1966). Most *Abies grandis* associations can be related to two major groups: (1) *Abies grandis/Pachistima myrsinites* and *Abies grandis/Vaccinium membranaceum*[21] (Daubenmire 1952; Daubenmire and Daubenmire 1968; Head 1959; Swedberg 1961; Hall 1967) and (2) the *Abies grandis/Calamagrostis rubescens* (Hall 1967; Johnson 1959).

The *Abies grandis/Pachistima myrsinites* and */Vaccinium membranaceum* associations have well-developed herbaceous understories. Characteristic species include:

Shrubs — *Rosa gymnocarpa*, *Pachistima myrsinites*, *Ribes lacustre*; and

Herbs — *Bromus vulgaris*, *Galium triflorum*, *Smilacina stellata*, *Thalictrum occidentale*, *Arnica cordifolia*, *Mitella stauropetala*, *Arenaria macrophylla*, *Hieracium albiflorum*, *Linnaea borealis*, *Adenocaulon bicolor*, *Anemone piperi*, *A. lyallii*, *Viola glabella*, *Trillium ovatum*, *Clintonia uniflora*, *Asarum caudatum*, *Lupinus latifolius*, and *Rubus lasiococcus*.

Under very dense canopies, a group of sciophytes forms a sparse understory (fig. 112) [the *Pirola-Corallorrhiza* union of Oosting and Billings (1943) again]; typical species are *Chimaphila umbellata*, *C. menziesii*, *Coralorhiza maculata*, *Pyrola asarifolia*, *P. secunda*, *P. picta*, *Monotropa hypopitys*, and *Listera convallarioides*.

The *Abies grandis/Calamagrostis rubescens* association is typically found on volcanic ash soils in the Ochoco and Blue Mountains.[22] It also has a herb-rich understory characterized by *Calamagrostis rubescens*, *Carex geyeri*, *C. concinnoides*, *Arnica cordifolia*, *Lupinus caudatus* and *Hieracium albiflorum*. Hall[23] and Johnson (1959) have recognized variants in which understory shrubs such as *Spiraea*, *Rosa*, *Salix*, and *Symphoricarpos albus* are typical. On upper slopes in the Ochoco and Blue Mountains, the *Abies/Calamagrostis* and *Abies/Vaccinium* associations generally occupy the south and north slopes, respectively.

The *Abies concolor/Ceanothus velutinus* association of south-central Oregon has much higher shrub and lower herbaceous coverage than the Abies grandis associations (Dyrness and Youngberg 1966). *Ceanothus velutinus*, *Arctostaphylos nevadensis*, and *A. patula* are the major shrubs. *Stipa occidentalis*, *Carex*

[21] F. C. Hall (personal communication) has described three related *Abies grandis* associations in the Blue Mountains province to which we have referred by the collective term, "the *Abies grandis/Vaccinium membranaceum* type." These are: *Abies grandis/Vaccinium membranaceum* (by far the most widespread), *Abies grandis/Bromus vulgaris* (southern Blue Mountains), and *Abies grandis/Linnaea borealis* (northern Blue Mountains).

[22] F. C. Hall (1967) and personal communication.

[23] F. C. Hall (1967) and personal communication.

Figure 112. — Understory vegetation is sparse under dense stands in the *Abies grandis* Zone; *Abies grandis-Pseudotsuga menziesii* forest in the Blue Mountains of Oregon (range pole is marked in 1-foot segments).

Figure 113. — *Pinus contorta* is a common seral species in the *Abies grandis* zone of eastern Oregon; *Abies grandis* and *Picea engelmannii* succeeding *Pinus contorta* in the Blue Mountains of Oregon (range pole is marked in 1-foot segments).

rossii, *Sitanion hystrix*, *Gayophytum diffusum*, *Cryptantha affinis*, *Fragaria cuneifolia*, *Epilobium angustifolium*, *Chimaphila umbellata*, and *Apocynum androsaemifolium* make up most of the sparse herbaceous layer.

Successional Patterns

Data on early successional stages following logging or burning on *Abies grandis* habitats are scarce. *Cirsium vulgare* was a major species on a clearcut and burned area in the Wallowa Mountains (Pettit 1968); *Ceanothus sanguineus*, *Physocarpus malvaceus*, *Spiraea betulifolia*, var. *lucida*, *Astragalus* sp., *Fragaria* spp., *Carex rossii*, *Epilobium paniculatum*, *Bromus tectorum*, and *Rumex acetosella* were also noted. Later in preforest succession, shrub communities are encountered in the *Abies grandis* Zone, at least in eastern Washington and northern Idaho (Daubenmire 1952; Mueggler 1965). Typical shrub invaders (Daubenmire and Daubenmire 1968) are *Salix scouleriana*, *Spiraea betulifolia* var. *lucida*, *Ceanothus velutinus*, *C. sanguineus*, *Amelanchier alnifolia*, *Sambucus cerulea*, and *S. racemosa* var. *melanocarpa*. Mueggler (1965) related the composition of these shrub communites to type of originating disturbance and age.

Throughout much of the *Abies grandis* and *Abies concolor* Zones in the Cascade Range, *Ceanothus velutinus* is again a major brushfield dominant, often behaving ecologically as described for southwestern Oregon. *Ceanothus velutinus* and species such as *Castanopsis chrysophylla* and *Arctostaphylos patula* may form a sclerophyll scrub following wildfires in the central and southern Oregon *Abies grandis-A. concolor* Zones.

As mentioned, *Pinus contorta*, *P. ponderosa*, and *Pseudotsuga menziesii* often dominate seral stands in the *Abies grandis* Zone. Fires were most important in instigating these stands, although they were generally less frequent than in the more xeric *Pinus ponderosa* Zone. In the Blue Mountains, *Pinus contorta* is a common seral species on *Abies grandis/Vaccinium membranaceum* habitats and *Pinus ponderosa* is typically successional to *Abies grandis/Calamagrostis rubescens.*[24] Most of the *Pinus contorta* forest described by Trappe and Harris (1958) is seral to *Abies grandis* (fig. 113). Sites occupied by *Pinus contorta* forests may go through a period of dominance by *Pseudotsuga menziesii* or *Picea engelmannii* prior to development of climax *Abies grandis* forests. *Pinus ponderosa* is the typical seral species on *Abies concolor/Ceanothus velutinus* habitats (Dyrness and Youngberg 1966) and *Pseudotsuga menziesii* is typical on *Abies grandis/Pachistima myrsinites* habitats in eastern Washington (Daubenmire 1952).

Larix occidentalis is a major seral dominant in parts of the Blue Mountains (*Abies grandis/Vaccinium membranaceum* habitats) and eastern Washington and can form a nearly pure type following repeated fires (fig. 114). *Picea engelmannii* is not ubiquitous in the *Abies grandis* Zone, but may be common in some areas; it is replaced only gradually since reproductive vitality is often high. *Pinus monticola* is an important species in localized areas. *Libocedrus decurrens* occurs sporadically as a seral species within the zone in the Cascade Range south of Mount Hood.

[24] F. C. Hall, personal communication.

Figure 114. — *Larix occidentalis* **forms nearly pure, seral stands in parts of the** *Abies grandis* **and** *Pseudotsuga menziesii* **Zones after fires; 30-year-old** *Larix* **reproduction on an old burn (near Twin Lakes, Colville National Forest, Washington).**

Most of the seral species attain optimum growth in the *Abies grandis* Zone. Daubenmire (1961) found that *Pinus ponderosa* grew better on *Abies grandis/Pachistima myrsinites* habitats than on sites where *Pseudotsuga menziesii* or *Pinus ponderosa* were climax. In Montana, *Larix occidentalis* grew better in the *Abies grandis* than in the cooler *Abies lasiocarpa* or drier *Pseudotsuga menziesii* Zones (Roe 1967). Selective logging of *Pinus ponderosa* within the *Abies grandis* Zone has produced strong successional pressures toward its elimination since reproduction is composed of more tolerant species. Forestry practices are shifting toward clearcutting of old-growth forest, partially to eliminate rotted *Abies* and partially to favor the *Pinus*.

Abies grandis or *A. concolor* are the major climax species. In some areas, *Pseudotsuga menziesii* may play a minor climax role. There are locations where *Abies grandis*-dominated forests occur which are themselves subject to replacement by the more tolerant *Abies amabilis*, *Tsuga heterophylla*, or *Thuja plicata;* these are considered elsewhere in this paper.

Special Types

Nonforest communities are common in many parts of the *Abies grandis* Zone. Some of these (discussed earlier) are successional to forest and others are climax shrub or grassland communities which are covered in the discussions of the *Pinus ponderosa* and *Abies lasiocarpa* Zones. Mountain meadows are the most important single group of permanent nonforest communities in the *Abies grandis* Zone.

Mountain meadow communities are conspicuous, essentially permanent, herbaceous communities, typically found on relatively gentle topography along and near the heads of stream courses (fig. 115). These are not subalpine communities and, though associated with zones from the *Abies lasiocarpa* to *Pinus ponderosa*, they are probably most typical of the *Abies grandis* Zone.

Deschampsia caespitosa, a perennial grass, typifies the dense herbaceous cover of climax mountain meadow communities (Reid and Pickford 1946) (fig. 116). Other major species

Figure 115. — Mountain meadows are common on gentle topography along and near the heads of stream courses in the *Abies grandis* Zone; they constitute an important grazing resource.

Figure 116. — *Deschampsia caespitosa*, a perennial grass, dominates mountain meadow communities in good condition.

are *Festuca rubra*, *Carex* spp., *Juncus balticus*, *Aster occidentalis*, *Polygonum bistortoides*, *Trifolium* spp., and *Senecio* spp.

Most *Deschampsia* meadows have been overgrazed by domestic livestock (fig. 115) and have deteriorated into other kinds of communities. Reid and Pickford (1946) recognized four major steps in deterioration: (1) perennial grass or climax, (2) mixed grass and weed (fig. 117), (3) perennial weed, and (4) annual weed. Serious erosional problems are associated with these changes in community composition. Major dominants in the perennial weed stage are *Senecio* spp., *Achillea millefolium* var. *lanulosum*, *Wyethia* spp., *Potentilla* spp., *Aster occidentalis*, *Taraxacum officinale*, and *Poa pratensis*. The annual weed stage is characterized by *Bromus mollis*, *Muhlenbergia filiformis*, *Polygonum douglasii*, and *Madia* spp. Development of climax vegetation from these deteriorated communities is usually extremely slow, even if grazing is completely eliminated.

"TSUGA HETEROPHYLLA" ZONE

Habitats where *Tsuga heterophylla* or *Thuja plicata* are climax are encountered on the eastern slopes of the Cascade Range in Washington and northern Oregon. These constitute the *Tsuga heterophylla* Zone. It is essentially an eastern extension of the widespread coastal *Tsuga heterophylla* Zone, although the composition of seral forests and understory is somewhat altered. This inland *Tsuga heterophylla* Zone correlates with the Interior Western Hemlock Zone in British Columbia (Krajina 1965, Bell 1965, Smith 1965) and the *Tsuga heterophylla* series of Daubenmire and Daubenmire (1968).

Interior *Tsuga heterophylla* and *Thuja plicata* forests are most common in the eastern Washington Cascades at elevations between 800 and 1,200 meters. In Oregon, they are increasingly rare to their southern limit at about 44° 30′ north latitude. Both species are absent from the Blue and Wallowa Mountains. Habitats sufficiently mesic to support *Tsuga heterophylla* or *Thuja plicata* are very often disjunct, occurring within areas of *Abies grandis* Zone.

Environmental Features

Environmental data are not available for the *Tusga heterophylla* Zone; however, the zone occurs under what appears to be the most equitable climatic regime of all the interior forest zones. Krajina (1965) indicated a precipitation range of 560 to 1,700 millimeters and mean annual temperatures of 2.5° to 7.5° C. for the zone in British Columbia. Major great soil groups are Brown Podzolic, Podzolic, and Gray-Brown Podzolic, including some with gleyed subsoils.

Forest Composition

Forest tree species found within the *Tsuga heterophylla* Zone include most of those found in the adjacent *Abies grandis* and *Abies lasiocarpa* (or *Tsuga mertensiana*) Zones. *Pseudotsuga menziesii*, *Abies grandis* and *Pinus monticola* are the most abundant seral species (table 17). It is in this zone in northern Idaho that the well-known western white pine (*Pinus monticola*) forests are best developed (fig. 118). *Thuja plicata* and *Tsuga heterophylla* are typically present together, although *Thuja plicata* is sometimes found on sites too xeric for *Tsuga heterophylla.*

Daubenmire and Daubenmire (1968) have described four *Tsuga* or *Thuja* associations in eastern Washington and northern Idaho: *Tsuga heterophylla/Pachistima myrsinites*, *Thuja plicata/Oplopanax horridum*, *Thuja plicata/Pachistima myrsinites*, and *Thuja plicata/Athyrium filix-femina.* The *Tsuga heterophylla/Pachistima myrsinites* is the most important. *Thuja plicata* is usually present, but it does not reproduce well. The understory is composed of the floristically rich *Pachistima* union (Daubenmire 1952) discussed earlier, the most constant species being *Pachistima myrsinites*, *Tiarella unifoliata*, *Vaccinium membranaceum*, *Clintonia uniflora*, and *Dryopteris linnaeana.* The *Thuja plicata/Oplopanax horridum* association is found in low-lying situations in association with the *Tsuga /Pachistima* association. Stands belonging to the *Thuja/Oplopanax* have a dense understory including a shrub layer dominated by *Oplopanax horridum*, many members of the *Pachistima* union, *Athyrium filix-femina*, and *Dryopteris dilatata.* Successional relations in stands are unclear; reproductive vigor variously indicates *Tsuga heterophylla* and/or *Thuja plicata* may be climax. Associations comparable to both of these were recognized by Bell (1965).

Figure 117. — Most mountain meadows have been severely overgrazed by domestic livestock, resulting in major compositional changes.

The *Thuja plicata/Pachistima myrsinites* and *Thuja plicata/Athyrium filix-femina* associations constitute a comparable pair outside the range of *Tsuga heterophylla*. The *Pachistima* union typifies the understory in the first and a variety of mesic-site herbs and *Alnus sinuata* in the second. *Abies grandis* is a major long-lingering seral species in the *Thuja plicata/Pachistima myrsinites* association; *Thuja plicata* is the major climax species in both.

Successional Patterns

Early stages in forest succession on disturbed sites have been discussed by Daubenmire (1952), Daubenmire and Daubenmire (1968) and Mueggler (1965). Shrub communities are

Figure 118. — Many seral species, such as the *Pinus monticola* shown here, attain their best development in the mesic *Tsuga heterophylla* and *Abies grandis* Zones.

often conspicuous prior to development of a tree overstory. Most of the *Tsuga heterophylla* Zone on the eastern slopes of the Cascade Range is occupied by relatively youthful stands in which the seral *Abies grandis*, *Pseudotsuga menziesii*, *Pinus monticola*, *Larix occidentalis*, *Pinus contorta*, and *Picea engelmannii* are dominant. *Tsuga heterophylla* and *Thuja plicata* are often represented only by reproduction in these stands.

The successional relationships between *Tsuga heterophylla*, *Thuja plicata*, and *Abies grandis* are complex. Daubenmire and Daubenmire (1968) state:

> Three species of trees in the *Tsuga* series [*Abies grandis*, *Tsuga heterophylla*, *Thuja plicata*] show . . . an ability to continue reproduction . . . but all have distinctive autecologies so that for the most part only one is the climax dominant in any one habitat type.

It is on this basis they recognize each as the major climax in one or more of the *Tsuga heterophylla* series of associations.

"ABIES LASIOCARPA" ZONE

Climax forests of *Abies lasiocarpa* characterize the subalpine forest zone at many locations in eastern Washington and Oregon. The *Abies lasiocarpa* Zone is best represented on the high secondary ranges extending east from the crest of the Washington Cascade Range (Franklin and Trappe 1963), in the Okanogan Highlands province of northeastern Washington, and in the Blue and Wallowa Mountains of northeastern Oregon (Daubenmire 1952; Johnson 1959; Head 1959). Its lower elevational boundary is normally 1,500 meters or more in the Cascade Range and 1,300 to 1,700 meters elsewhere. The *Abies lasiocarpa* Zone is a more continental analog of the *Tsuga mertensiana* Zone with which it merges in the Cascade Range. It is the local representative of the very widespread Rocky Mountain *Abies lasiocarpa-Picea engelmannii* forests (Oosting 1956) and correlates with the Englemann Spruce-Subalpine Fir Zone recognized in British Columbia (Krajina 1965), the *Abies lasiocarpa* Zone of the northern Rocky Mountains (Daubenmire and Daubenmire 1968), and Merriam's Hudsonian Life Zone (Barrett 1962).

The *Abies lasiocarpa* Zone may be bounded at its lower limits by forests in which *Tsuga heterophylla*, *Thuja plicata*, *Abies grandis*, or *Pseudotsuga menziesii* are climax, depending upon locale. Where mountain masses are sufficiently high, it extends upward to the subalpine-alpine ecotone and, in these cases, typically includes an area of forest-meadow parkland. As with the *Tsuga mertensiana* Zone, we will concern ourselves only with the closed forest portion of the *Abies lasiocarpa* Zone in this section.

Abies lasiocarpa-Picea engelmannii forests are often conspicuous in frost pockets and other habitats characterized by drainage and accumulation of cold air. These often occur well below the expected elevational limits for the *Abies lasiocarpa* Zone. In the Washington Cascade Range, the best developed *Abies lasiocarpa-Picea engelmannii* forest occur in glaciated valley bottoms and not on the mountain slopes.

Environmental Features

Environmental data are extremely scarce for the *Abies lasiocarpa* Zone. It is the coolest and moistest of the forested zones. Cool summers, cold winters, and development of deep winter snowpacks are more important factors than total precipitation in differentiating the *Abies lasiocarpa* from lower forested zones, however. Mean annual temperatures probably range from about 2.5° to 4.5° C. Climatically, the *Abies lasiocarpa* Zone is more continental than the *Tsuga mertensiana* Zone, with lower winter and higher summer temperatures and lesser precipitation and snowpack accumulations, on the average.

Zonal soils in the *Abies lasiocarpa* Zone are generally Podzols or Brown Podzols with well-developed but relatively thin mor humus layers. Regosolic and lithosolic soils are also common in some localities. Soils are more acid than in the lower forested zones — typically pH 4.5 to 5.9.

Forest Composition

Major forest tree species in the *Abies lasiocarpa* Zone are *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus contorta* (fig. 119). *Pseudotsuga menziesii*, *Abies grandis*, *Larix occidentalis*, and *Pinus monticola* may be conspicuous lower in the zone; *Pinus albicaulis* and, sometimes, *Larix lyallii* are abundant higher in the zone. *Pinus ponderosa* and *Populus tremuloides* are relatively uncommon. *Abies amabilis*, *A. procera*, and *Tsuga mertensiana* may be encountered as minor stand components, although locally *Tsuga mertensiana* dominates stands disjunct from the *Tsuga mertensiana* Zone.

Daubenmire and Daubenmire (1968) recognized five *Abies lasiocarpa* associations in eastern Washington and northern Idaho: *Abies lasiocarpa/Pachistima myrsinites*, *Abies lasiocarpa/Xerophyllum tenax*, *Abies lasiocarpa/Menziesia ferruginea*, *Abies lasiocarpa/Vaccinium scoparium*, and *Pinus albicaulis-Abies lasiocarpa*. The first three associations tend to form a topographic series within the zone: the *Abies/Pachistima* occupies the lowest part of the zone, *Abies/Xerophyllum* is typical of upper south slopes and ridgetops, and *Abies/Menziesia* occupies the wettest and coolest sites — north slopes and ravines. The *Abies/Pachistima* association has representatives of the *Pachistima* union (Daubenmire 1952) as its understory; *Clintonia uniflora* and *Galium triflorum* are especially well represented. Many species occur only in this association and nowhere else in the *Abies lasiocarpa* Zone: *Acer glabrum*, *Arnica cordifolia*, *Hieracium albiflorum*, *Amelanchier alnifolia*, *Aster conspicuus*, *Mitella stauropetala*, *Actaea rubra*, *Clintonia uniflora*, *Coptis occidentalis*, *Viola glabella*, *Adenocaulon bicolor*, *Rubus parviflorus*, *Arenaria macrophylla*, *Galium triflorum*, and *Spiraea betulifolia*. In the *Abies/Xerophyllum* association, the depauperate understory is dominated by *Xerophyllum tenax* and *Vaccinium membranaceum*. The *Abies/Menziesia* association has a well-developed shrub layer in which *Menziesia ferruginea* is sometimes combined with *Rhododendron albiflorum* or *Ledum glandulosum*. In northern Idaho, Daubenmire and Daubenmire (1968) have also recognized comparable *Menziesia ferruginea* and *Xerophyllum tenax* associations in which *Tsuga mertensiana* is the characteristic tree species.

The *Abies lasiocarpa/Vaccinium scoparium* association is widespread (Daubenmire and

Daubenmire 1968; Johnson 1959) and seems particularly common in drier locales. *Vaccinium scoparium* is the major understory species; typical associates are *Juniperus communis*, *Vaccinium membranaceum*, *V. caespitosum*, *Carex* spp., *Hieracium albiflorum*, *Arnica cordifolia*, and *Aster* spp. (Illingworth and Arlidge 1960).

The *Pinus albicaulis-Abies lasiocarpa* (Daubenmire and Daubenmire 1968) and *Abies lasiocarpa-Picea engelmannii* (Head 1959) associations described within the zone are relatively open forest types associated with the subalpine parkland.

Successional Patterns

Preforest successional developments in the *Abies lasiocarpa* Zone are poorly known. Herbaceous stages characterized by species such as *Epilobium angustifolium* may occur. Shrub communities similar to those found in lower forested zones (Daubenmire and Daubenmire 1968; Mueggler 1965) may develop on the most moderate sites; i.e., those potentially occupied by the *Abies lasiocarpa/Pachistima myrsinites* association. Elsewhere, disturbed areas are usually dominated by the same species that make up the forest understory — e.g., *Xerophyllum tenax*, *Vaccinium membranaceum*, and *Menziesia ferruginea*.

Successional relationships among tree species in the *Abies lasiocarpa* Zone are better understood. *Pinus contorta* is one of the most ubiquitous and conspicuous of the seral species. *Picea engelmannii* is also very important in many areas and conflicting opinions are common regarding its successional status. In the Rocky Mountains, some workers have concluded *Picea engelmannii* is a climax species (Oosting and Reed 1952), others that it is subclimax (Fowells 1965). Daubenmire and Daubenmire (1968) state that *Picea engelmannii* is a major climax species only in the *Abies lasiocarpa/Vaccinium scoparium* association; it is a persistent long-lived seral species in five other associations and a minor climax component in the *Abies lasiocarpa/Pachistima myrsinites* association. The subtle trend toward elimination of *Picea engelmannii* was not considered in an earlier treatment (Daubenmire 1952) in which *Picea engelmannii-Abies lasiocarpa* associations and a zone were proposed. Franklin and Mitchell (1967) concluded *Abies lasiocarpa* generally replaces *Picea engelmannii* on the eastern slopes of Washington's Cascade Range.

The relationship between *Tsuga mertensiana* and *Abies lasiocarpa* is not completely clear. Locally, *Tsuga mertensiana* is a dominant species in the northern Rocky Mountains *Abies lasiocarpa* Zone (Daubenmire and Daubenmire 1968; Habeck 1967). Sometimes it appears to be the major climax species, but in others reproduction of *Abies lasiocarpa* is also abundant. Factors differentiating sites with and without *Tsuga mertensiana* in this area have not been determined (Daubenmire and Daubenmire 1968). In some parts of Washington's eastern Cascade Range, and even as far south as central Oregon (Sherman 1969), disjunct populations of *Tsuga mertensiana* occur mixed with *Abies lasiocarpa* in which resolution of the successional question is not clear. Within the main *Tsuga mertensiana* Zone in the Cascade Range, *Abies lasiocarpa* is almost always seral, however (Franklin and Mitchell 1967).

Hence, *Abies lasiocarpa* is the major and often sole climax species within the closed forest portion of the *Abies lasiocarpa* Zone of eastern Washington and Oregon. Only occasionally do *Picea engelmannii* or *Tsuga mertensiana* challenge its dominance there.

Special Types

Permanent nonforest communities dominated by herbs or shrubs occur within the forest matrix. Many of these are clearly extensions of subalpine meadow types and will be discussed later. Two, more characteristic of the closed-forest portion of *Abies lasiocarpa* Zone, are grassy parks and *Artemisia tridentata* var. *vaseyana* communities.

Grassy parks or balds are frequently encountered on or near ridgetops in the *Abies lasiocarpa* Zone (Daubenmire and Daubenmire 1968; Secor 1960; Johnson 1959; Hall 1967) (fig. 120). These are typically dominated by grasses such as *Agropyron spicatum*, *Festuca idahoensis*, and *F. viridula*, although

Figure 119. — Mixed stands of *Abies lasiocarpa* and *Picea engelmannii* typify the subalpine forests in more continental mountain areas.

many other species may be conspicuous — e.g., *Hieracium albertinum*, *Arenaria capillaris* var. *americana*, and *Polygonum phytolaccaefolium* in northern Idaho and *Artemisia arbuscula*, *Phlox* spp., *Poa secunda*, and *Achillea millefolium* in the Ochoco Mountains. A lower fringe of *Prunus emarginata* is sometimes present. These grasslands are associated with south-facing slopes and are more xeric than adjacent forest stands (Daubenmire 1968b). Whatever their origin, wind-transfer of moisture (snow) from these balds and soil

Figure 120. — Wind transfer of snow and soil drought are important in maintaining grassy balds or parks frequently found on south slopes near ridgetops in the *Abies lasiocarpa* Zone (*photo courtesy R. Daubenmire*).

drouth seem important in maintaining them as topographic climaxes.

Artemisia tridentata var. *vaseyana*, a cold-requiring diploid ancestor of *Artemisia tridentata* var. *tridentata*, characterizes another group of nonforest communities associated with the *Abies lasiocarpa* Zone (as well as lower forest zones) (Daubenmire 1969; Johnson 1959; Hall 1967). *Carex* spp., *Agropyron spicatum*, and *Festuca idahoensis* are typical associates.

STEPPE VEGETATION

In the rain shadow of the Cascade Range is a large region of steppe and shrub-steppe vegetation including most of central and southeastern Washington and much of eastern Oregon. This is the region of the bunchgrass and sagebrush communities (Shantz and Zon 1924). Typical community dominants include shrubs such as *Artemisia tridentata*, *Purshia tridentata*, *Artemisia rigida*, *A. arbuscula*, and *Atriplex confertifolia*, large perennial grasses such as *Agropyron spicatum*, *Festuca idahoensis*, *Elymus glaucus*, and *Stipa thurberiana*, and alien invaders such as *Bromus tectorum*, *Poa pratensis*, and *Elymus caput-medusae*. Forest vegetation is generally confined to mountain slopes with sufficient precipitation, either regionally (e.g., approaching the Rocky Mountains) or locally (e.g., higher elevations on interior ranges such as the Blue Mountains).

Climatically, the steppe areas can be typified as arid to semiarid with low precipitation, warm-to-hot dry summers, and relatively cold winters (table 23). Some marine influences are still felt (conditions are not so extreme as those in the Great Basin, for example), but continental-type climatic conditions prevail.

Table 23. — Climatic data from representative stations within steppe areas of eastern Washington and Oregon

Station	Elevation	Latitude	Longitude	Temperature					Precipitation		
				Average annual	Average January	Average January minimum	Average July	Average July maximum	Average annual	June through August	Average annual snowfall
	Meters			Degrees C.					Millimeters		Centimeters
Ellensburg, Wash.	526	47°02′	120°31′	8.4	−4.7	−9.3	20.6	28.9	230	33	--
Moses Lake, Wash.	368	47°07′	119°12′	9.2	−3.9	−8.3	21.3	30.7	212	35	--
Kennewick, Wash.	119	46°13′	119°08′	12.0	−.2	−4.3	24.2	33.3	190	24	34
Pullman, Wash.	776	46°46′	117°12′	8.6	−2.2	−5.3	20.1	28.1	610	75	102
The Dalles, Oreg.	31	45°36′	121°12′	11.8	.1	−2.5	22.7	30.6	389	23	--
Pendleton, Oreg.	455	45°41′	118°51′	11.2	−.7	−4.3	23.1	33.2	320	44	47
Burns, Oreg.	1,265	43°35′	119°03′	7.8	−4.1	−9.7	20.2	29.8	289	43	122
Ontario, Oreg.	654	44°03′	116°58′	10.6	−2.5	−7.3	24.5	35.1	236	24	--
Lakeview, Oreg.	1,455	42°11′	120°21′	7.8	−2.6	−7.9	19.2	29.2	364	41	136

Source: U. S. Weather Bureau (1956, 1965a,b).

A great variety of soils occurs in the steppe region. The zonal sequence from the hottest, driest sites to the wettest of the steppe habitats would run through Sierozem, Brown, Chestnut, Chernozem and Prairie great soil groups. From soils with light-colored, thin A horizons poor in organic matter and calcium accumulations high in the profile (Sierozem), the soils grade to thick, very dark-brown to black A horizons rich in organic matter in which calcium carbonate accumulations may be deep in the profile or absent (Prairie). At the same time, the wide variety of intrazonal soils includes most notably those having accumulations of salts (Solonchak) and large amounts of exchangeable sodium (Solonetz).

Fire and grazing were apparently of limited importance in steppe vegetation before arrival of Europeans and their livestock (Daubenmire 1969, Heady 1968). Large herds of ungulates were never an integral part of the steppe communities in the Northwest as they were in the Great Plains. The limited grazing was confined to deer, wapiti, and antelope until arrival of the horse in the early 1700's. Cattle were introduced in the steppe vegetation in the early 19th century and sheep about 1860, and the latter were generally more abundant until about 1940.[25] Aboriginal man had little need to use fire in the steppes in contrast to forested regions or areas where he used fire as an adjunct in hunting.

Man has wrought massive changes in the steppe vegetation of the Northwest by the cultivation, animals, and plants he introduced. The best lands are cultivated almost entirely for wheat, peas, and similar crops. Some of the poorer lands, cropped for a time, have since been abandoned. Additional lands lacking sufficient natural moisture have been "reclaimed" through irrigation, most notably in the Columbia Basin province. Remaining lands have been subjected to various degrees of grazing and often overgrazed by domestic and feral livestock. Overgrazing was considered a serious problem more than 60 years ago (Griffiths 1902, 1903; Cotton 1904). Man-caused range fires were common in many steppe areas and still occur occasionally.

[25] Gerald S. Strickler, personal communication.

To appreciate how grazing and wildfire can affect the natural vegetation, one should consider features of some of the major climax dominants and alien invaders (Daubenmire 1969). These features are central to any consideration of succession and successional status in the steppes.

1. Some of the major shrub species, notably *Artemisia* spp. and *Purshia tridentata*, are fire sensitive and can be temporarily eliminated from a site by burning.[26]
2. Most of the major large perennial grasses, e.g., *Agropyron spicatum* and *Festuca idahoensis*, are not adapted to heavy grazing by ungulates. They evolved in an environment in which such animals were sparsely represented. They rarely recover to their former status after severe overgrazing, but are relatively insensitive to fire.
3. Two alien species, *Bromus tectorum* and *Poa pratensis*, are well adapted to parts of the steppe region. They will invade or increase under heavy grazing pressure (in their respective areas) and relinquish occupied sites to native vegetation either very slowly or not at all when grazing pressures are lifted. Hence, shifts to these species are generally only reversed by human intervention. Recently, another alien species, *Elymus caput-medusae* subsp. *asper*, has entered parts of the steppe region and threatens to further alter the ecology of the region.

The vegetation of the Northwestern steppes has been studied by many scientists. Early generalized accounts include those of Colville (1896), Griffiths (1902, 1903), Cotton (1904), Weaver (1917), Shantz and Zon (1924), and Aldhous and Shantz (1924). In recent years, more detailed reports cover synecological aspects of steppe and shrub-steppe vegetation in eastern Washington (Daubenmire 1940, 1942, 1956, 1966; McMinn

[26] Steppe shrub dominants are generally nonsprouting; *Purshia tridentata* exhibits widely varying sprouting behavior, depending on environmental conditions (Blaisdell 1953; Blaisdell and Mueggler 1956; Driscoll 1963).

1952; Cooke 1955; Daubenmire and Colwell 1942) and portions of eastern Oregon (Poulton 1955; Eckert 1957; McKell 1956; Tueller 1962). Anderson (1956) has divided eastern Oregon into ecological provinces; Humphrey (1945) has considered major range types in both States; and Billings (1951) constructed a general zonational approach to the Great Basin which is relevant to a part of southeastern Oregon.

From these accounts, it is possible to recognize numerous diverse community types, including many which would qualify as climatic climaxes (zonal associations) within a part of their range. In general, no single sequence of zonal belts of vegetation applies throughout the steppe region. Consequently, we focus attention on the steppes of Washington's Columbia Basin province, where the entire vegetational mosaic is most fully understood. Here a cross section of the communities encountered in the steppe regions of the Pacific Northwest can be illustrated and related; some similarities and differences between this region and the other major steppe region in central and southeastern Oregon will be suggested.

Columbia Basin Province of Eastern Washington

The Columbia Basin province of eastern Washington is a large, contiguous area of steppe and shrub-steppe vegetation — over 6,000,000 hectares. The vegetational mosaic of this area has been thoroughly studied (see earlier citations), and except as noted, this discussion is abstracted from the most recent regional account (Daubenmire 1969).

ZONAL ASSOCIATIONS

Nine zonal associations, communities which can occur as climatic climaxes, have been recognized in the steppe region of the Columbia Basin province. These are the:

Artemisia tridentata/Agropyron spicatum,
Artemisia tridentata/Festuca idahoensis,
Agropyron spicatum-Poa secunda,
Agropyron spicatum-Festuca idahoensis,
Festuca idahoensis/Symphoricarpos albus,
Festuca idahoensis/Rosa nutkana,
Artemisia tripartita/Festuca idahoensis,
Festuca idahoensis-Hieracium cynoglossoides, and
Purshia tridentata/Festuca idahoensis associations.

The last five associations are found on the periphery of the steppe region near its contact with forest vegetation. These tend to be lush, meadowlike communities with conspicuous amounts of large perennial grasses and broadleaved forbs. The term "meadow steppe" has often been applied to these types. The other four zonal associations lie in the more arid interior of the Columbia Basin province. Vegetation is more open and forbs are less conspicuous in these communities.

The nine zonal associations have differentiated in response to differences in temperature and total and seasonal distribution of precipitation. Where they occur on modal sites, as climatic climaxes, they characterize or distinguish regional units or zones of steppe vegetation. Four of these zones — the *Artemisia/Agropyron*, *Artemisia/Festuca*, *Agropyron-Festuca*, and *Festuca/Symphoricarpos* Zones — are encountered along a transect beginning in the driest part of the Columbia Basin province and extending eastward up the gentle slope of the Columbia plateau to foothills of the Rocky Mountains. They provide an exemplary cross section of the zonal associations. The composition of some stands found along this transect belonging to the zonal associations is shown in table 24. This tabulation includes only pristine stands found on zonal habitats (sites with gently undulating topography and deep, well-drained silt loam soils). The following association descriptions amplify this tabulation and encompass all stands belonging to the association under consideration, since any of these zonal associations may occur as a topographic climax in one or more adjacent zones.

Artemisia tridentata/Agropyron spicatum Association

The driest of the zones has as a climatic climax the *Artemisia/Agropyron* association (fig. 121). Four layers are found in this association: (1) a shrub layer composed principally

Table 24. — Percent canopy-coverage of species in climatic climax steppe communities along a 96-km. longitudinal transect extending from the center of the Columbia Basin province (left side of table) to the Washington-Idaho border (right side of table)[1]

Species	Association																					
	Artemisia/Agropyron							*Artemisia/Festuca*			*Agropyron-Festuca*					*Festuca/Symphoricarpos*					
Stipa thurberiana	5	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Poa cusickii	2	9	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Stipa comata	2	+	13	2	9	14	–	1	–	13	6	–	–	–	–	–	–	–	–	–	–	–
Artemisia tridentata	18	18	9	9	16	19	11	25	13	4	–	–	–	–	–	–	–	–	–	–	–	–
Chrysothamnus viscidiflorus	–	–	+	–	–	2	9	+	+	8	1	–	+	–	–	–	–	–	–	–	–	–
Plantago patagonica	–	–	14	8	–	11	–	–	3	6	3	7	2	2	+	–	–	–	–	–	–	–
Phlox longifolia	+	12	–	+	7	8	12	2	+	1	–	1	3	1	5	1	–	–	–	–	–	–
Erigeron filifolia	–	–	–	–	3	–	5	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–
Astragalus spaldingii	–	–	–	–	–	–	–	2	1	2	+	+	6	2	13	–	–	–	–	–	–	–
Poa secunda	40	50	29	61	55	73	36	44	38	5	19	39	16	23	45	2	+	2	+	+	+	
Achillea millefolium	–	–	–	+	–	+	+	–	+	2	1	2	3	1	+	22	10	6	9	25	25	
Agropyron spicatum	41	63	46	35	41	55	36	40	39	26	42	77	33	34	71	79	57	–	77	78	78	
Festuca idahoensis	–	–	–	–	–	–	–	9	23	39	29	7	71	75	8	81	30	41	35	40	40	
Senecio integerrimus	–	–	-	–	–	–	–	–	–	–	–	–	–	–	–	+	2	8	3	2	–	
Myosotis stricta	–	–	-	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	5	5	
Haplopappus liatriformis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	8	–	–	+	+	
Koeleria cristata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	3	–	+	4	4	
Hieraceum albertinum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	+	4	11	1	1	
Lupinus sericeus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	1	2	–	3	3	
Festuca scabrella	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	51	–	–	–	
Sidalcea oregana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8	–	–	–	–	
Castilleja lutescens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	2	9	5	5	
Arnica sororia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	+	
Solidago missouriensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	29	–	–	–	–	–	
Balsamorhiza sagittata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	41	14	51	51	
Helianthella uniflora	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	31	31	
Astragalus arrectus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18	18	
Poa ampla	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	57	53	–	–	–	–	
Rosa nutkana + R. woodsii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	–	+	1	1	
Iris missouriensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	29	–	2	1	1	
Potentilla gracilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	21	+	45	5	5	
Geranium viscosissimum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	21	+	4	–	–	
Galium boreale	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	11	–	–	1	1	
Symphoricarpos albus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	15	2	11	17	17	

Median annual precipitation 167 mm. ← → 526 mm.
Mean annual temperature 11.2°C. ← → 7.9°C.

[1] Species with maximum coverages of less than 5 percent omitted; plus sign indicates coverage of less than 1 percent (from Daubenmire 1966).

Figure 121. — The *Artemisia tridentata/Agropyron spicatum* association is the climatic climax in driest parts of the Columbia basin steppe region; the range pole is 4 feet tall and marked in 6-inch segments (*photo courtesy Range Management, Oregon State University*).

of *Artemisia tridentata* var. *tridentata* and 1 to 2 meters in height — very small amounts of other shrubs such as *Chrysothamnus viscidiflorus*, *C. nauseosus* var. *albicaulis*, *Artemisia tripartita* or *Grayia spinosa* may be present; (2) a layer of caespitose perennial grasses dominated by *Agropyron spicatum* — variable amounts of *Stipa comata*, *S. thurberiana*, *Poa cusickii*, or *Sitanion hystrix* may be present; (3) a layer of plants within 1 decimeter of the soil surface, including species such as *Poa secunda*, *Bromus tectorum*, and *Lappula redowskii*; (4) a surface crust typically composed of crustose lichens and acrocarpous mosses (e.g., *Tortula brevipes*, *T. princeps*, and *Aloida rigida*). Variation of *Artemisia tridentata* coverage in this association is from 5 to 26 percent, and this variation is not believed related to past grazing. Seasonal sequences in phenology are marked with mosses, small perennials, and annuals developing earliest and larger grasses and forbs flowering in June. Shrubs remain active all summer by tapping permanent moisture supplies in the subsoil; flowering extends from late June (*Tetradymia canescens*) to October (*Artemisia tridentata*).

This association is found on a wide variety of soils including those belonging to the Sierozem, Brown and Brown-Chestnut (intergraded) great soil groups.

Successional changes in the *Artemisia/Agropyron* Zone are most often associated with grazing, fire, or cultivation. Grazing most seriously affects the larger perennial grasses since they are preferred by cattle and sheep and are not adapted to withstand grazing. Heavy grazing tends, therefore, to eliminate *Agropyron spicatum*, *Festuca idahoensis*, *Poa cusickii*, etc., and to increase annual grasses, particularly *Bromus tectorum*. The smaller perennial *Poa secunda* is generally not signifi-

Figure 122. — *Artemisia tridentata* is sensitive to fire since it is a nonsprouter; the patchiness of *Artemisia* in this *Artemisia/Agropyron* community suggests the influence of past burning (*photo courtesy Range Management, Oregon State University*).

Figure 123. — A monotonous, herbaceous cover dominated by perennial grasses characterizes the climatic climax of the *Agropyron spicatum-Poa secunda* community (*photo courtesy Range Management, Oregon State University*).

cantly affected, and *Artemisia* suffers mechanical damage only if the grazing animals are cattle. *Bromus tectorum* will apparently relinquish ground only very slowly once grazing pressure is lifted. Fire seriously affects only one dominant, *Artemisia tridentata.* It is often completely killed by range fires, and although the remaining dominants can regenerate from subterranean organs, *Artemisia* must reoccupy the site by invasion and gradual expansion, a relatively slow process (fig. 122). A combination of both burning and overgrazing can result in development of an annual rangeland dominated by *Bromus tectorum* in which *Chrysothamnus nauseosus* may be the only significant shrub. Cropped and abandoned fields will also develop a community dominated by *Bromus tectorum*, but the tumbleweeds *Salsola kali* and *Sisymbrium altissimum* may dominate the old field for a year or two while the *Bromus* population builds up.

The *Artemisia/Agropyron* association is the most extensive element in the steppe mosaic of eastern Washington, and essentially identical communities are widely distributed elsewhere, including British Columbia (Tisdale 1947), central Oregon (Eckert 1957), southern Idaho, and Montana. Three other zonal associations (*Purshia/Festuca*, *Artemisia tripartita/Festuca*, and *Artemisia tridentata/Festuca*) can occur as topographic climaxes on moister sites within the *Artemisia/Agropyron* Zone. Conversely, the *Artemisia/Agropyron* association can occur as a topographic climax on drier sites in adjacent zones.

Artemisia tridentata/ Festuca idahoensis Association

East along the transect, a second large perennial grass, *Festuca idahoensis*, is added to climatic climax communities, indicating presence in a second zone typified by the *Artemisia tridentata/Festuca idahoensis* association (table 24). The significance of this addition has been discussed by Daubenmire (1966); the addition indicates the moisture balance of the macroclimate in this zone is more favorable for plant growth.

The only significant floristic difference between the *Artemisia/Festuca* and *Artemisia/Agropyron* association is the addition of *Festuca idahoensis* as a major grass (table 24).

Artemisia tridentata remains the dominant shrub. Soils associated with this association belong to the Brown or Solonetz great soils groups. Response of the *Artemisia/Festuca* community to fire or grazing is essentially the same as that of the *Artemisia/Agropyron* association.

Agropyron spicatum-Festuca idahoensis Association

Eventually a point is reached on transect where *Artemisia tridentata* drops from climax communities on zonal habitats (table 24). This leaves a monotonous herbaceous cover dominated by perennial grasses (fig. 123). Again, this change indicates an improved moisture regime (Daubenmire 1966) and a third zone, the *Agropyron spicatum-Festuca idahoensis* Zone.

The definitive *Agropyron spicatum-Festuca idahoensis* association is dominated by these two perennial grasses plus *Poa secunda*. There are few forbs; and *Artemisia tridentata*, *A. tripartita*, *Symphoricarpos albus*, and *Rosa* spp. do not occur in this association (table 24). *Opuntia polyacantha* may be a minor climax species south of the Snake River. The *Agropyron-Festuca* association occurs on a wide variety of soils, including those belonging to Brown, Chestnut, Chernozem, Planosol, Solodized-Solonetz, and Prairie-Grumosol (intergraded) great soil groups. Fire has little effect on this community since neither of the dominants is seriously affected. As in the prior associations, *Bromus tectorum* is the main increaser with grazing.

Festuca idahoensis/ Symphoricarpos albus Association

The fourth and moistest of the steppe zones is the *Festuca idahoensis/Symphoricarpos albus* Zone (fig. 124). Here, a whole group of species is added (table 24), producing a luxurious meadow-steppe (Daubenmire 1966). This zone has as its climax the *Festuca idahoensis/Symphoricarpos albus* association.

Figure 124. — The vegetational mosaic in the *Festuca idahoensis/Symphoricarpos albus* Zone includes herb-rich meadow steppe dominated by *Festuca* and *Agropyron spicatum*, thickets of low shrubs such as *Symphoricarpos* and *Rosa*, and taller thickets of *Crataegus douglasii* in moist draws (*photo courtesy Range Management, Oregon State University*).

Figure 125. — The climax grasslands of the *Festuca idahoensis/Symphoricarpos* Zone in the Columbia basin are sometimes referred to as meadow-steppe because of the dense cover of sod-forming grasses and the abundance of broad-leaved herbs (*photo courtesy R. Daubenmire*).

The *Festuca/Symphoricarpos* association has a dense herbaceous layer dominated by *Festuca idahoensis* and *Agropyron spicatum* (fig. 125). The *Agropyron spicatum* on this site is rhizomatous, not caespitose as is the case in drier associations. A rich assemblage of other perennial grasses and broad-leaved forbs are associated with these grasses (table 24). Some of the more conspicuous are *Hieracium albertinum*, *Lupinus sericeus*, *Castilleja lutescens*, *Balsamorhiza sagittata*, *Helianthella uniflora*, *Astragalus arrectus*, *Poa ampla*, *Iris missouriensis*, *Potentilla gracilis*, *Geranium viscosissimum* and *Koeleria cristata*. The assemblage of grasses and forbs discussed here is common to the peripheral ring of meadow-steppe associations referred to earlier. It is the shrub component (or lack of same) which distinguishes them. Dwarfed sterile *Rosa nutkana*, *R. woodsii*, and *Symphoricarpos albus* are present but inconspicuous. Associated soils belong to the Chernozem, Prairie, and Planosol great soil groups.

Within the herbaceous matrix described above are thickets of shrubs 0.5 to 3 meters in height which have been recognized as a *Symphoricarpos albus* phase of the *Festuca/Symphoricarpos* association. These thickets may be 4 to 25 meters in diameter and consist primarily of *Symphoricarpos albus*, a low marginal zone of *Symphoricarpos* around a core of *Rosa* spp., or even a core of *Prunus virginiana* with marginal belts of *Rosa* and *Symphoricarpos*. Herbaceous species are the same as in adjacent grassland, except highly sciophytic species may be purged and all are

reduced in stature. There is no evidence these shrub thickets are spreading; grassland and shrub thickets form a stable mosaic.

Fire has little effect on the *Festuca/Symphoricarpos* association, since all important species can regenerate from underground organs. Heavy grazing results in a major and irreversible change, however; perennial grasses, shrubs, and most forbs are eliminated, and an invader, *Poa pratensis*, becomes dominant. The *Poa pratensis* community is not replaced with the elimination of grazing and can become an essentially pure sward. This replacement of native grasses and herbs by *Poa pratensis* is characteristic of all habitats (except lithosolic sites) in the *Festuca/Symphoricarpos*, *Festuca/Rosa*, and lower forested zones.

ASSOCIATIONS ON SPECIALIZED HABITATS

Within the steppe region are a wide variety of habitats which have soils sufficiently unusual in physical or chemical properties to develop climax communities not assignable to any of the zonal associations. Some of these are associated with particular zones as defined by the nine zonal associations; many are not. Consequently, some of the associations typical of such sites are handled separately in this section.

Sandy or Gravelly Soils

Deep soils dominated by gravel or sand have low moisture-holding capacity. Associations found on such soils within the drier interior steppe zones share a dominance of *Stipa comata*. In this series of *Stipa comata* associations, a shrubby species is usually present: *Artemisia tridentata*, *A. tripartita*, or *Purshia tridentata*. These shrub dominants appear insensitive to soil differences so conspicuously reflected in the compositional shift of the herbaceous cover.

Lithosols

Lithosolic sites are those where soils are stony and extremely shallow to bedrock. These sites provide an extremely rigorous plant environment, with heat and drought in the summer and intense frost action (the result of excess water) during the winter. The lithosolic series of associations have in common a carpet of *Poa secunda*, a crust of mosses and lichens, and a lithosolic substrate (fig. 126). Nearly all associations have a taller layer of shrubs, but the species vary — *Eriogonum niveum*, *E. sphaerocephalum*, *E. douglasii*, *E. compositum*, *E. thymoides*, *E. microthecum*, or *Artemisia rigida*. Many stands are outstandingly dominated by a single shrub species but others have dominance divided between several. Several plant groups — *Allium*, *Eriogonum*, *Lomatium*, Cruciferae — have their best steppe representation in the lithosolic associations.

The *Artemisia rigida/Poa secunda* association is the most widespread member of this series. It occurs on Lithosols from the *Artemisia/Agropyron* Zone to the *Pseudotsuga menziesii* Zone in eastern Washington, and south to central and southeastern Oregon.

Saline-Alkali Soils

A carpet of *Distichlis stricta* links the associations found on saline-alkali soils which are high in salts, sodium ion, and pH. *Distich-*

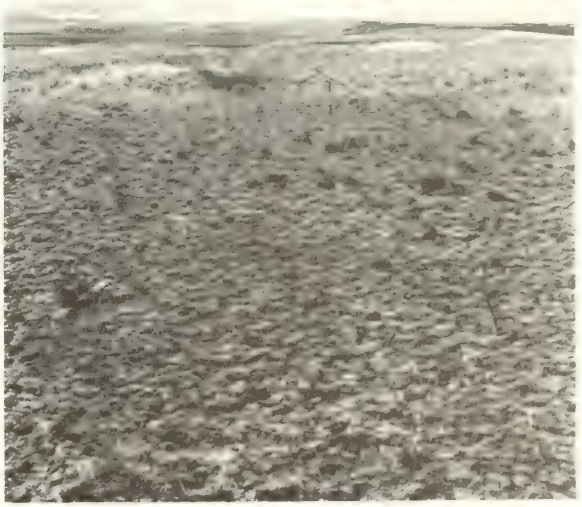


Figure 126. — **Lithosolic sites in the Columbia basin steppe region are occupied by a series of associations of which the *Poa secunda-Eriogonum niveum* is one; range pole is 4 feet tall and marked in 6-inch segments (*photo courtesy Range Management, Oregon State University*).**

lis is a low (herbage less than 20 cm. high), perennial, strongly rhizomatous grass. Superimposed on this sward may be an open stand of either *Sarcobatus vermiculatus* (a deciduous, succulent-leaved shrub) or *Elymus cinereus* (a large, coarse bunchgrass). Lack of a moss-lichen crust between the vascular plants is notable. Of the three dominants, *Elymus* appears least tolerant of high salinity and pH.

Crataegus douglasii Associations

On moister sites within the *Festuca/Symphoricarpos* and *Festuca/Rosa* Zones, the *Crataegus douglasii-Symphoricarpos albus* and *Crataegus douglasii/Heracleum lanatum* associations may occur. Both have a nearly complete woody plant cover 5 to 7 meters tall which is dominated by *Crataegus douglasii.* The *Crataegus-Symphoricarpos* association is typically found in moist draws and includes *Symphoricarpos albus* and many herbs common to the *Festuca/Symphoricarpos* association. Some examples are *Galium boreale, Geranium viscosissimum, Iris missouriensus,* and *Potentilla gracilis. Spiraea betulifolia, Crataegus columbiana, Prunus virginiana,* and *Amelanchier alnifolia* are often present.

The *Crataegus/Heracleum* association is found on aggraded valley floors. Understory dominants are *Heracleum lanatum, Hydrophyllum fendleri* var. *albifrons,* and *Urtica dioica,* singly or collectively. Only *Lomatium dissectum* is shared with the *Festuca/Symphoricarpos* or *Festuca/Rosa* associations. However, many elements more common in forested zones may be present, such as *Circaea alpina, Elymus glaucus, Geum macrophyllum,* and *Pteridium aquilinum.*

Most sites, potentially occupied by these associations, have been heavily grazed and replaced with a sward of *Poa pratensis* and *Poa compressa* along with exotic forbs such as *Cirsium vulgare, Dipsacus sylvestris,* and *Taraxacum officinale.*

Populus tremuloides may occur in either of these communities, and such stands are recognized as phases of the respective associations. In drier zones, *Populus trichocarpa/Cicuta douglasii* association replaces the *Crataegus douglasii/Heracleum lanatum* association in similar topographic situations.

Shrub/*Poa secunda* Associations

Within the lowest, dryest part of the *Artemisia/Agropyron* Zone is a series of three associations found on reasonably deep, loamy soils which are drier than those on associated zonal habitats. These are the *Artemisia tridentata/Poa secunda, Grayia spinosa/Poa secunda,* and *Eurotia lanata/Poa secunda* associations. These associations lack a large perennial grass and, in fact, the species used in the names are often nearly the only vascular plants present. The *Eurotia lanata/Poa secunda* association is found on the hottest and dryest sites of this series. It is associated with highly calcareous Regosols.

Colluvium, Alluvium, and Talus

A series of associations typified by *Rhus glabra* are found on colluvial or alluvial soils in canyons in the *Agropyron-Poa* and *Artemisia/Agropyron* Zones. Most *Rhus glabra* stands are heavily grazed, and *Bromus tectorum* and annuals such as *Erodium cicutarium* usually are understory dominants. When a dominant perennial grass is present, it can be *Agropyron spicatum, Sporobolus cryptandrus,* or *Aristida longiseta.*

A *Celtis douglasii/Bromus tectorum* association typifies colluvial cones and aprons in the *Agropyron-Poa* Zone. A *Grayia spinosa/Bromus tectorum* community can be found on talus in some areas. Shrub "garlands" of *Philadelphus lewisii, Prunus virginiana* var. *melanocarpa, Amelanchier alnifolia,* and *Rosa* spp. are typical talus margins in the interior steppe zones (fig. 127).

Sand Dunes

Sand dunes are a common phenomenon near the Columbia River in the lowest part of the Columbia Basin province. *Psoralea lanceolata* is found on active windward slopes of some of these dunes. *Elymus flavescens* can be found on high dune summits, and *Rumex venosus* or *Agropyron dasystachyum* on slip faces of active dunes. Stabilized dune surfaces can have communities of *Chrysothamnus nauseosus* and *C. viscidiflorus, Agropyron das-*

Figure 127. — Shrub garlands of *Philadelphus lewisii*, *Prunus virginiana*, and *Amelanchier alnifolia* are typically found around talus in the interior of the Columbia basin (*photo courtesy R. Daubenmire*).

ystachyum, *Oryzopsis hymenoides*, *Koeleria cristata*, *Poa secunda*, *Achillea millefolium* var. *lanulosa*, *Microsteris gracilis*, *Descurainia pinnata*, and *Holosteum umbellatum*. The *Artemisia tridentata/Stipa comata* association has been noted on very old dune surfaces. *Juniperus scopulorum* savanna is found on some of the sand dunes.

Oregon Steppe and Shrub-Steppe

Steppe and shrub-steppe communities are widespread in Oregon, dominating the entire southeastern quarter of the State and a strip around the northwestern and western margins of the Blue Mountains. The communities found in the latter area, near the Columbia River, are very similar to those described in the section on the Columbia Basin province (Poulton 1955; Anderson 1956). Therefore, we will confine this section to the shrub-steppe of southeastern Oregon; i.e., the High Lava Plains, Basin and Range, and Owyhee Uplands provinces (fig. 2).

In some respects, the steppes of southeastern Oregon are similar to those of the Columbia Basin province: (1) both areas have hot, dry summers and cold winters; and (2) there are similar communities, e.g., the *Artemisia tridentata/Agropyron spicatum* and *Artemisia tridentata/Festuca idahoensis* associations. Contrasts between the two areas are notable, however: (1) southeastern Oregon shrub-steppes average much higher in elevation; (2) deep, loamy soils are not common in southeastern Oregon; (3) desert or salt desert shrub communities are common enough to appear on regional vegetation maps; (4) *Juniperus occidentalis* and *Cercocarpus ledifolius* occur in association with shrub-steppe; and (5) meadow-steppes of sod-forming grasses and dicotyledonous herbs, which ring much of the

Figure 128. — *Artemisia* **communities dominate the shrub-steppe of southeastern Oregon; in this High Lava Plains province landscape,** *Artemisia tridentata* **communities occur on the hills,** *Artemisia arbuscula* **communities on the shallow soils of basalt flows, and** *Artemisia cana* **communities in seasonally ponded valley bottoms (***photo courtesy Range Management, Oregon State University***).**

Columbia Basin province, are nearly absent. Hence, although the physiognomy and dominants of many communities are often similar, the environmental and community mosaics are different.

The steppe and shrub-steppe communities of southeastern Oregon have not been comprehensively treated. Nevertheless, from the generalized accounts of Poulton (1962), Anderson (1956), and Shantz and Zon (1924) and detailed but localized work by Eckert (1957), Dean (1960), Tueller (1962), Culver (1964), Dealy (1969), and McKell (1956), many of the important community types in the vegetational mosaic emerge.

"ARTEMISIA" COMMUNITIES

Artemisia communities dominate nearly every vegetational mosaic in southeastern Oregon's shrub-steppe (fig. 128). There are four major *Artemisia* species, each of which characterizes particular habitats:

Artemisia tridentata on the deeper soils,
Artemisia arbuscula on shallow, stony soils,
Artemisia rigida on very shallow soils (Lithosols), and
Artemisia cana on moister habitats.

Associations of *Artemisia tridentata*, *A. arbuscula*, and *A. rigida* have been described in detail (Eckert 1957; Culver 1964; Hall 1967); lists of characteristic species for six of these associations are provided in table 25.

Artemisia tridentata/ Agropyron spicatum Association

The *Artemisia tridentata/Agropyron spicatum* association is very similar to the Columbia Basin province association of the same name (fig. 129); it is the most widespread as-

Figure 129. — **The** *Artemisia tridentata/Agropyron spicatum* **community is probably the most widespread single type in southeastern Oregon and contains the same dominants as in the Columbia basin; the range pole is 2-1/2 feet tall and marked in 6-inch segments (***photo courtesy Range Management, Oregon State University***).**

Table 25. — Characteristic species for *Artemisia* associations found in the High Lava Plains (Eckert 1957), Owyhee Upland (Culver 1964), and southern Blue Mountains (Hall 1967) provinces

Association	Species group	High Lava Plains	Owyhee Uplands	Southern Blue Mountains
Artemisia tridentata/	Shrubs	*Artemisia tridentata*	*Artemisia tridentata*	
Agropyron spicatum	Grasses	*Agropyron spicatum*	*Agropyron spicatum*	
		Poa secunda	*Poa secunda*	
	Herbs	*Phlox diffusa*	*Lupinus sericeus*	
		Aster scopulorum	*Lomatium triternatum*	
		A. canescens	*L. macrocarpum*	
		Chaenactis douglasii	*Zygadenus paniculatus*	
		Collinsia parviflora	*Microseris troximoides*	
		Phlox gracilis	*Astragalus filipes*	
		Lappula redowskii	*A. lentiginosus*	
		Gayophytum ramosissimum		
Artemisia tridentata/	Shrubs	*Artemisia tridentata*	*Artemisia tridentata*	
Festuca idahoensis		*Chrysothamnus viscidiflorus*	*Chrysothamnus viscidiflorus*	
		Symphoricarpos rotundifolius		
		Ribes cereum		
		Juniperus occidentalis		
	Grasses	*Festuca idahoensis*	*Festuca idahoensis*	
		Agropyron spicatum	*Agropyron spicatum*	
		Poa secunda	*Poa secunda*	
		Koeleria cristata	*Sitanion hystrix*	
			Bromus tectorum	
			Elymus cinereus	
	Herbs	*Phlox diffusa*	*Balsamorhiza sagittata*	
		Antennaria corymbosa		
		Calochortus nitidus		

Table 25 — Continued

Association	Species group	High Lava Plains	Owyhee Uplands	Southern Blue Mountains
Artemisia tridentata/	Shrubs		*Artemisia tridentata*	
Elymus cinereus	Grasses	(mentioned but not described)	*Elymus cinereus*	
			Poa secunda	
			Agropyron spicatum	
			Bromus tectorum	
	Herbs		*Penstemon speciosus*	
			P. cusickii	
			Thlaspi arvense	
			Eriogonum umbellatum	
Artemisia arbuscula/	Shrubs	*Artemisia arbuscula*	*Artemisia arbuscula*	*Artemisia arbuscula*
Agropyron spicatum		*Eriogonum sphaerocephalum*		*Purshia tridentata*
		Juniperus occidentalis		
	Grasses	*Agropyron spicatum*	*Agropyron spicatum*	*Agropyron spicatum*
		Poa secunda	*Poa secunda*	*Poa secunda*
		Festuca idahoensis	*Sitanion hystrix*	*Sitanion hystrix*
			Bromus tectorum	
	Herbs	*Phlox diffusa*	*Penstemon aridus*	*Trifolium macrocephalum*
		Erigeron linearis	*Lagophylla ramosissima*	
		Collinsia parviflora		
Artemisia arbuscula/	Shrubs	*Artemisia arbuscula*	*Artemisia arbuscula*	*Artemisia arbuscula*
Festuca idahoensis		*Juniperus occidentalis*		
	Grasses	*Festuca idahoensis*	*Festuca idahoensis*	*Festuca idahoensis*
		Agropyron spicatum	*Agropyron spicatum*	*Agropyron spicatum*
		Poa secunda	*Poa secunda*	*Poa secunda*

Table 25 — Continued

Association	Species group	High Lava Plains	Owyhee Uplands	Southern Blue Mountains
	Herbs	*Phlox diffusa*	*Arabis holboellii*	*Phlox douglasii*
		P. hoodii	*Phlox diffusa*	*Balsamorhiza serrata*
		P. longifolia	*Erigeron linearis*	
		Microseris troximoides	*Astragalus miser*	
		Antennaria dimorpha	*Balsamorhiza hookeri*	
		Astragalus stenophyllus	*Agoseris heterophylla*	
		Lupinus saxosus	*Achillea millefolium*	
		Trifolium gymnocarpon	*Haplopappus stenophyllus*	
		T. macrocephalum		
Artemisia rigida/	Shrubs		*Artemisia rigida*	*Artemisia rigida*
Poa secunda	Grasses		*Poa secunda*	*Poa secunda*
			Bromus tectorum	*Sitanion hystrix*
			Festuca pacifica	
			Agropyron spicatum	
			Sitanion hystrix	
	Herbs		*Mimulus nanus*	*Phlox douglasii*
			Zygadenus paniculatus	

sociation in southeastern Oregon. Eckert (1957) and Culver (1964) recognized the *Artemisia tridentata/Agropyron* association as the climatic climax in their areas (High Lava Plains and Owyhee Uplands provinces, respectively). Eckert (1957) found it a highly variable community in which *Artemisia tridentata* was the only important shrub (average coverage 10 percent). *Agropyron spicatum* was the dominant grass and *Poa secunda* the typical associate in both localities. The component of perennial and annual herbs differed considerably between the High Lava Plains and Owyhee Uplands provinces, however (table 25). Eckert (1957) noted an abundance of annual herbs. *Tortula ruralis* was a conspicuous mass in the leaf-fall area of the shrubs. *Festuca idahoensis* and *Stipa thurberiana* are typically minor elements, but *Festuca* and *Stipa* phases (as well as *Purshia tridentata* phases) of the association have been described or listed (Culver 1964; Eckert 1957). The *Festuca* phase

Figure 130. — Larger perennial grasses have been found to decrease under grazing pressure, although *Poa secunda* may increase, and *Artemisia tridentata* appears little affected; top, the area to the left of the fence (lacking *Agropyron spicatum*) has been continuously and heavily grazed, and the area to the right has been protected for 8 years; and bottom, an *Artemisia tridentata/Poa secunda* community which has developed under heavy cattle grazing (*photos courtesy Range Management, Oregon State University*).

Figure 131. — *Chrysothamnus viscidiflorus* dominates the abandoned cultivated land in the foreground; the *Artemisia tridentata* island (right background) has never been plowed (*photo courtesy Range Management, Oregon State University*).

occupies more mesic sites and the *Stipa* phase more xeric sites than the typical association.

Tueller (1962) compared grazed and ungrazed *Artemisia tridentata/Agropyron spicatum* stands along fence lines and in enclosures. The important perennial grasses — *Agropyron spicatum*, *Festuca idahoensis*, and *Stipa thurberiana* — decreased with grazing (fig. 130). *Poa secunda* and many of the herbs increased with grazing. *Artemisia tridentata* was indeterminant; significant changes in its status with grazing were not found. *Chrysothamnus* spp. varied in response, increasing in some cases and appearing indeterminant in others. *Bromus tectorum* or *Chrysothamnus* spp., or both, dominate many severely overgrazed areas as well as abandoned farmland (fig. 131).

Soils associated with the *Artemisia/Agropyron* association belonged to the Brown great soil group, were usually moderately deep (60 to 80 cm. to cemented layers or bedrock), and usually had well-developed, clay B horizons.

Artemisia tridentata/ Festuca idahoensis Association

The *Artemisia tridentata/Festuca idahoensis* association is a topographic or topoedaphic climax on sites more mesic than those

Figure 132. — *Artemisia arbuscula* typically dominates communities on shallower, stonier soils than those found under *Artemisia tridentata*; this is an *Artemisia arbuscula/Festuca idahoensis* community on the High Lava Plains province of central Oregon (*photo courtesy Range Management, Oregon State University*).

Figure 133. — *Artemisia rigida* dominates the *Artemisia rigida/Poa secunda* association widespread on lithosolic sites throughout the steppes and drier forests of eastern Oregon and Washington (*photo courtesy Range Management, Oregon State University*).

occupied by the *Artemisia tridentata/Agropyron* association (Culver 1964; Eckert 1957). *Artemisia tridentata* is the dominant shrub, although *Chrysothamnus viscidiflorus* is an important minor component. *Festuca idahoensis*, *Poa secunda*, and *Agropyron spicatum* are dominant grasses. The grass and perennial herb associates differ in the two study areas (table 25). The more mesic nature of Eckert's stands is indicated by occurrence of rhizomatous *Agropyron spicatum*, *Symphoricarpos rotundifolius*, *Ribes cereum*, and *Juniperus occidentalis* as typical constituents.

In the Owyhee Uplands province, Culver (1964) found the *Artemisia tridentata/Festuca* association on Brown soils. In the High Lava Plains province (Eckert 1957), it was the only association found on Chestnut as well as Brown soils. In any case, these soils had higher moisture storage capacities than those supporting adjacent *Artemisia tridentata/Agropyron spicatum* communities.

Artemisia tridentata/Elymus cinereus Association

Culver (1964) describes and Eckert (1957) mentions an *Artemisia tridentata/Elymus cinereus* association which occurred primarily on moist alluvial bottom lands. Culver (1964) and Anderson (1956) mention occurrence of such a type on uplands, as well. *Artemisia tridentata* and *Chrysothamnus viscidiflorus* are the characteristic shrubs. *Elymus cinereus* is always conspicuous and sometimes dominates the ground layer. Culver (1964) mentions several herbs which were restricted to this association in the Owyhee Uplands (table 25).

Artemisia arbuscula Associations

Artemisia arbuscula has a much lower growth form (1 to 4 dm.) than *A. tridentata* which also dominates large portions of the eastern Oregon shrub-steppe. Two major *Artemisia arbuscula* associations have been recognized: *Artemisia arbuscula/Agropyron spicatum* and *A. arbuscula/Festuca idahoensis* (fig. 132) (Eckert 1957; Culver 1964; Hall 1967). *Artemisia arbuscula*, *Agropyron spicatum*, and *Poa secunda* are the major species in the *Artemisia arbuscula/Agropyron spicatum* association. A variety of associates is present depending upon locale (table 25). *Artemisia arbuscula*, *Festuca idahoensis*, *Poa secunda*, *Agropyron spicatum*, and a variety of perennial herbs distinguish the *Artemisia arbuscula/Festuca idahoensis* association (table 25).

These associations typically occur with *Artemisia tridentata* communities as edaphic climaxes on shallow, stony phases of the zonal Brown soils. The *Agropyron* type occupies

more xeric sites than the *Festuca* type in the steppe area (Culver 1964; Eckert 1957). Where they occur within a forest mosaic (Ochoco Mountains), the *Agropyron* type is on about 35 centimeters of clayey soil derived from basic igneous rock and the Festuca type is on comparable soils from acid igneous rock (Hall 1967).

Tueller (1962) studied effects of grazing in habitats characterized by the *Artemisia arbuscula/Festuca idahoensis* association. He found the larger perennial grasses — *Festuca idahoensis*, *Sitanion hystrix*, *Agropyron spicatum*, and *Koeleria cristata* — decreased with grazing. *Chrysothamnus visicidiflorus*, *Poa secunda*, and a variety of herbs increased whereas amounts of *Artemisia arbuscula* remained constant under grazing.

Artemisia rigida/ Poa secunda Association

Artemisia rigida is the shrub dominant of the *Artemisia rigida/Poa secunda* association (fig. 133). This association is widespread on lithosolic sites (Culver 1964; Hall 1967; Daubenmire 1969). *Artemisia rigida* is normally the only shrub present; average coverage was about 20 percent in the Owyhee area (Culver 1964). *Poa secunda* is the dominant grass (cover 40 percent). Other typical grasses and herbs are listed in table 25.

This association is always found on very shallow, stony soils. Hall (1967) reported 15 centimeters of soil as typical of *Artemisia rigida* habitats compared with 35 centimeters on *Artemisia arbuscula* habitats.

Other *Artemisia* Associations

Several other *Artemisia*-dominated communities have been mentioned by various authors. These include:

Community	Location	Source
Artemisia tridentata-Chrysothamnus spp.	High Lava Plains province	Eckert (1957)
Artemisia tridentata-Chrysothamnus nauseosus/Stipa thurberiana	Sand hills; Owyhee Uplands province	Culver (1964)
Artemisia tridentata-Grayia spinosa	Steep, south-exposed talus; Owyhee Uplands province	Culver (1964) Dean (1960)
Artemisia tridentata-Sarcobatus vermiculatus/Stipa thurberiana	Slopes; High Lava Plains and Owyhee Uplands provinces	Eckert (1957) Dean (1960)
Artemisia tridentata/Stipa comata-Carex spp.	Sandy soils; High Lava Plains province	Eckert (1957)
Artemisia tridentata-Purshia tridentata	High Lava Plains, Basin and Range, Blue Mountains provinces	Eckert (1957) Tueller (1962) Dealy (1969)
Artemisia tridentata/Stipa occidentalis-Lathyrus bijugatus	Basin and Range province	Dealy (1969)
Artemisia tridentata-Purshia tridentata/Festuca idahoensis	Basin and Range province	Dealy (1969)
Artemisia arbuscula/Danthonia unispicata	Basin and Range province	Dealy (1969)
Artemisia arbuscula/Koeleria cristata	Basin and Range province	Dealy (1969)
Artemisia cana/Muhlenbergia-Juncus	Basin and Range province	Dealy (1969)

STATUS OF "JUNIPERUS OCCIDENTALIS"

Juniperus occidentalis is sometimes associated with *Artemisia tridentata* and *A. arbuscula* communities throughout much of central and southeastern Oregon. In the High Lava Plains province, its occurrence is related to more mesic microhabitats (Eckert 1957); *Juniperus* is typical of escarpments and rock outcrops, mesic northerly slopes (with *Artemisia arbuscula/Festuca idahoensis* communities), and intermittent drainage ways in this area. Soil depths are commonly greater under trees than under adjacent *Artemisia.* In some locales of the High Lava Plains province, *Juniperus occidentalis* is sufficiently common that *Juniperus* associations or phases of shrub-steppe associations are recognized; unique microcommunities and soil properties are associated with the trees (Eckert 1957). A *Juniperus occidentalis* belt is recognized at 1,750- to 1,950-meter elevation in the Steens Mountains (Hansen 1956); *Artemisia arbuscula* is its most typical associate there. *Juniperus* also occurs along the Owyhee River canyon (Head 1959).

DESERT OR SALT DESERT SHRUB

Communities variously designated as desert shrub, salt desert shrub, shadscale (*Atriplex confertifolia*), salt sage (*Atriplex nuttallii*), or saltbush-greasewood (*Atriplex-Sarcobatus*) have been mapped but described in only general terms (Shantz and Zon 1924; Poulton 1962; Küchler 1964; Hansen 1956). These communities are on saline soils and often intermingled with upland communities dominated by *Artemisia tridentata.* Salt desert shrub communities are most common in the Basin and Range province,where interior drainage and old lakebeds are typical.

Important shrubs in these communities can include *Grayia spinosa, Atriplex confertifolia, A. nuttallii, Eurotia lanata, Artemisia spinescens,* and *Sarcobatus vermiculatus.* Grasses sometimes associated with these shrubs include *Elymus cinereus, E. triticoides* (which may dominate on ancient lakebeds), and *Distichlis stricta.* An *Atriplex confertifolia/Sitanion hystrix* community with some *Artemisia spinescens, Eurotia lanata, Poa secunda,* and *Oryzopsis hymenoides* is one of the most common communities. *Sarcobatus vermiculatus/Distichlis stricta* communities are also typical of some of the moister saline habitats.

The desert shrub communities are much better developed to the south and east where they dominate extensive areas (Shantz and Zon 1924; Billings 1949, 1951).

GRASSLAND COMMUNITIES

Steppe communities lacking a major shrub constituent, such as the grassy types so abundant in the *Agropyron-Festuca* and *Festuca/Symphoricarpos* Zones of the Columbia Basin province (Daubenmire 1969), are not common in southeastern Oregon (fig. 134). Johnson (1959) described an *Agropyron spicatum-Poa secunda* Zone on the southeastern slopes of the Wallowa Mountains in which two steppe communities were recognized:

Agropyron spicatum-Poa secunda, the most extensive community with *Balsamorhiza sagittata* and *Eriogonum heracleoides* as associates, and

Figure 134. — Steppe communities lacking a major shrub dominant are not common in southeastern Oregon; where they do occur, burning may have been responsible, as in this *Agropyron spicatum-Lygodesmia spinosa* community located near Fort Rock, Oregon (*photo courtesy Range Management, Oregon State University*).

Festuca idahoensis-Agropyron spicatum, an uncommon community with *Balsamorhiza* and *Bromus brizaeformis* as typical constituents.

The *Agropyron-Poa* community also occurred on Lithosols in the adjacent *Pseudotsuga menziesii* Zone (Johnson 1959). A similar community was noted by Dean (1960) in a part of the Owyhee River canyon and by Hall[27] in the Blue Mountains.

Hall also described a *Poa secunda-Danthonia unispicata* association which occurs on Lithosols throughout much of eastern Oregon. This scabland community generally replaces the *Artemisia rigida-Poa secunda* type on less permeable bedrock.

"CERCOCARPUS LEDIFOLIUS" COMMUNITIES

Communities dominated by *Cercocarpus ledifolius* are often found in the ecotone between *Pinus ponderosa* and *Artemisia* shrub-steppe in central Oregon (fig. 135) (Dealy 1969); *Cercocarpus* also forms pure stands at higher elevations in some of the mountain ranges of extreme southeastern Oregon, particularly in the Mahogany Mountains. Dealy (1969) recognized two associations in central Oregon: *Cercocarpus ledifolius/Festuca idahoensis* and *Cercocarpus/Festuca-Agropyron spicatum*. *Pinus ponderosa*, *Juniperus occidentalis*, *Artemisia tridentata*, *Ribes cereum*, and *Chrysothamnus viscidiflorus* are typical shrub or arborescent associates in both associations, but *Cercocarpus ledifolius* is strongly dominant with 36- and 66-percent crown cover, respectively. The chief difference in herbaceous understory is codominance of *Festuca idahoensis* and *Agropyron spicatum* in the *Cercocarpus/Festuca-Agropyron* community. *Agropyron spicatum*, *Sitanion hystrix*, *Koeleria cristata*, and *Poa secunda* are minor components of the *Festuca*-dominated understory in the *Cercocarpus/Festuca* community. These communities are important browse types for deer which often leave browse-lines on larger *Cercocarpus* and hedge younger plants.

[27] F. C. Hall, personal communication.

Figure 135. — *Cercocarpus ledifolius* communities are common in the forest-steppe ecotone in central Oregon; *Chrysothamnus nauseosus* is the major associate in this stand (Deschutes National Forest, Oregon).

"PURSHIA TRIDENTATA" COMMUNITIES

Purshia tridentata is a dominant in poorly known but widespread communities, particularly near the foothills of the Cascade Range. Dealy (1969) has described two of these: *Purshia tridentata-Artemisia arbuscula/Stipa thurberiana* and *Purshia tridentata/Festuca idahoensis* communities which are found near the forest-steppe ecotone in central Oregon. Similar communities are also found in the southern Blue Mountains[28] and southeastern Wallowa Mountains (Johnson 1959). As mentioned earlier, *Purshia* is codominant with *Artemisia tridentata* on some sites within the steppe proper.

RIPARIAN COMMUNITIES

A rich variety of poorly known community types is found on riparian or other moist sites within the southeastern Oregon shrub-steppe. *Populus tremuloides* communities or colonies are common near the forest-steppe transition (Dealy 1969). *Populus tremuloides* is also extremely conspicuous between 1,950-

[28] F. C. Hall, personal communication.

Figure 136. — *Populus tremuloides* **is conspicuous between elevations of 1,950 and 2,400 meters on Steens Mountain in southeastern Oregon;** *Populus* **groves are typically associated with wet meadows in this landscape mosaic.**

and 2,400-meter elevation in the Steens Mountains, forming the only widespread arborescent communities there (fig. 136) (Hansen 1956). The herbaceous understory is often lush in these communities.

Other types include riparian *Salix-Crataegus*, *Salix-Prunus*, and *Elymus cinereus* communities (Dean 1960; Hansen 1956), wet *Carex* meadows (Hansen 1956), and the tule marshes of the Klamath Lake area in which *Scirpus validus* is an important dominant (Shantz and Zon 1924).

TIMBERLINE AND ALPINE VEGETATION

On the highest mountain ranges of Oregon and Washington are subalpine parklands and alpine meadows. The parklands constitute an ecotone in which tree dominance is gradually giving way under the increasingly harsh alpine environment. Typically, the area between forest line[29] and scrub line is a mosaic of tree patches and meadow communities (fig. 137), the former gradually being reduced in area and in stature as elevations increase. This belt was referred to as the Hudsonian Zone by Merriam (Bailey 1936). In western Washington and British Columbia, it has been split into two units by Krajina (1965) and Franklin (1966) depending on occurrence of trees as a climatic or topographic climax. In this fashion, a part is considered the upper segment of

[29] We recognize three types of timberline: *forest line*, the general upper limit of contiguous closed forest; *tree line*, the upper limit of erect arborescent growth; and *scrub line*, the general upper limit of krummholz (= elfinwood or wind-timber line) (Arno 1966; Habeck and Hartley 1968). Our timberline region in this discussion covers the entire area from forest line to scrub line.

Figure 137. — Timberline regions are typically mosaics of tree groups, meadows, snow patches, and rock outcrops (Jefferson Park, Willamette National Forest, Oregon).

the *Tsuga mertensiana* Zone (Parkland Subzone) and the other constitutes the lower part of the Alpine Zone.

In any case, the entire forest-meadow mosaic of the region between forest and scrub line is the major topic of this section. Alpine communities will be considered briefly; many of them or their variants are components of the timberline mosaic. However, alpine communities, sensu above scrub line, are neither well developed nor well known in the Pacific Northwest, as will be seen.

Occurrence of Timberline Regions

Elevations sufficient to develop true timberline conditions are encountered generally in the northern Cascade Range and Olympic Mountains in Washington and in the Wallowa Mountains of Oregon. Further south in the Cascade Range, major peaks such as Mount Rainier, Mount Hood, and Three Sisters have sufficient elevation to develop a climatic timberline and alpine regions. Timberline environments are occasionally encountered in the Blue, Steens, and Warner Mountains of Oregon and the Okanogan Highlands and Rocky Mountain outliers of eastern Washington.

Average elevation of forest and scrub line at representative Oregon and Washington locations is listed in table 26. It can be seen that the timberline mosaics generally involve a 300- to 500-meter elevational band. Elevations of forest and scrub line vary with exposure on an order of ± 150 meters, dropping on cool, northerly exposures and rising on warmer, southerly exposures (Bailey 1936; Arno 1966). Timberline elevations decrease

Table 26. — Average elevation of forest and scrub line at selected locations in Oregon and Washington

Area	Latitude	Longitude	Forest line	Scrub line
			Meters	
Mount Baker	48°45′	121°50′	1,400	1,750
Wenatchee Mountains	47°30′	120°45′	2,000	2,440
Mount Rainier	47°10′	121°40′	1,580	2,100
Mount St. Helens	46°15′	122°10′	1,340	--
Mount Hood	45°20′	121°45′	1,680	1,980
Three Sisters	44°10′	121°50′	1,980	2,290
Mount McLoughlin	42°50′	122°20′	2,130	2,440
Olympic Mountains (central)	47°45′	123°30′	1,460	1,890
Olympic Mountains (northeast)	47°50′	123°20′	1,680	1,980
Wallowa Mountains	45°10′	117°20′	--	2,700

Source: Partially from Arno (1966), Bailey (1936), and Brockman (1949)

notably with increasing latitude; Daubenmire (1954) indicates the general tendency is for timberline to drop about 110 meters per degree of increase in latitude under a given climatic regime. The forest and scrub lines are markedly lower in coastal mountain regions (dominated by a maritime climate) than they are further inland. For example, forest line is about 500 meters higher at the eastern edge of the Cascade Range than it is at the same latitude on the western edge.

Timberline Tree Species

A great many tree species occur in timberline areas, some of which are listed in table 27. *Abies lasiocarpa*, *Tsuga mertensiana*, *Pinus albicaulis*, and *Larix lyallii* are characteristic, however. *Abies lasiocarpa* is the most widespread, occurring in all timberline areas except in parts of southern Oregon. Near forest line, it is usually abundant as an erect tree dominating the islands of forest (fig. 138). It is reduced to a shrubby krummholz form at higher elevations where it often forms dense mats by layering.

Tsuga mertensiana is widely distributed at timberline throughout all but the most xeric portions of the Cascade Range and Olympic Mountains. In the most maritime portions of these ranges, it is usually more important than *Abies lasiocarpa*; timberline on Mount Baker is completely dominated by *Tsuga mertensiana* and both *Abies lasiocarpa* and *Pinus albicaulis* are very rare. Its timberline growth behavior is like that of *Abies lasiocarpa* (fig. 139).

Figure 138. — *Abies lasiocarpa* is the most widespread of the timberline tree species; pictured are groups of this species near timberline in the eastern Cascade Range (Wenatchee National Forest, Washington).

Table 27. — Tree species typically found between forest line and timberline in selected parts of Washington and Oregon

Species	Cascade Range			Olympic Mountains, Washington	Wallowa Mountains, Oregon
	Northwestern Washington	Northeastern Washington	Central Oregon		
Abies amabilis	m	—	m	m	—
Abies lasiocarpa	M	M	M	M	M
Abies magnifica var. *shastensis*	—	—	m	—	—
Chamaecyparis nootkatensis	m	—	—	m	—
Larix lyallii	—	M	—	—	—
Picea engelmannii	—	m	—	—	m
Pinus albicaulis	m	M	M	m	M
Pinus contorta	—	m	m	m	m
Tsuga mertensiana	M	—	M	M	—

Note: M = major species; m = minor species.

Pinus albicaulis is present in most timberline areas. However, it is unquestionably most important in more xeric regions — eastern and southern parts of the Cascade Range and Okanogan and Wallowa Mountains, or locally, on the eastern rain-shadow slopes of the major volcanoes such as Mount Rainier and Mount Hood. *Pinus albicaulis* is able to grow erect to higher elevations than either *Abies lasiocarpa* or *Tsuga mertensiana* although it will form krummholz at its upper limits. It sometimes functions as a pioneer tree species in invasion of meadow areas (Franklin and Mitchell 1967). The wingless seeds of *Pinus albicaulis* are distributed primarily by the Clark's nutcracker (*Nucifraga columbiana*), a large jay, which consumes a portion of the seed crop and hoards the rest. Reproduction develops from the forgotten hoards (fig. 140). Their relationship is the same as that described for *Pinus cembra-Nucifraga caryocatactes* in the European Alps and for *Pinus pumila-Nucifraga caryocatactes* var. *japonicus* in Japan.

Larix lyallii is, with rare exception, limited to the eastern half of the northern Cascade Range and Okanogan Mountains in Washington. It occurs only at or near timberline in these areas and appears exceptionally well adapted to the environment (fig. 141). *Larix lyallii* typically grows to higher elevations than any of its associates and maintains an erect habit when other species are unable to grow or occur only as krummholz beneath the *Larix*. As a result, *Larix lyallii* stands often form a distinctive forest belt between forest and alpine; this belt is particularly conspicuous during the fall as a swath of brilliant orange yellow.

Many other species do occur in localized timberline areas. *Chamaecyparis nootkatensis* is a major krummholz species in parts of the Washington Cascade Range and northeastern Olympic Mountains. *Pinus contorta* is typical in more xeric timberline tracts in association with *Pinus albicaulis*. *Picea engelmannii* is occasional at timberline east of the Cascade crest. *Abies amabilis* is common below the tree line in the most maritime portions of the Cascade Range and Olympic Mountains. *Abies magnifica* var. *shastensis* and *Pinus monticola* occupy similar sites in the southern Oregon Cascade Range (e.g., at Crater Lake).

Figure 139. — *Tsuga mertensiana* is an important timberline tree species throughout most of the Cascade Range and Olympic Mountains.

Figure 140. — *Pinus albicaulis* **is a major timberline tree species in drier mountain areas; reproduction of the species is largely dependent upon the hoarding habits of a large jay,** *Nucifraga columbiana,* **which give rise to groups of seedlings and saplings (Sunrise Ridge, Mount Rainier National Park, Washington).**

Meadow Communities

The variety and richness of the meadow flora and communities make the subalpine parkland attractive to scientists and laymen alike. Many of the species (and communities in the broad sense) are circumpolar. The mosaic of meadow communities is an intricate and often sharp response to local variations in substrate, moisture conditions, and duration of winter snowpack.

Even within the Pacific Northwest, the dominant meadow communities in the parkland mosaic and lower alpine vary from area to area just as the tree species do. Many communities occur throughout and retain their same basic character over a wide geographic range, but their importance in the mosaic changes. We will consider first the meadow communities found in a cooler and moister maritime region, the western slopes of Washington, and then outline some different meadow types characteristic of southern Oregon and of the interior mountain ranges.

WESTERN WASHINGTON

The meadow communities found in the subalpine parkland of western Washington are not well known. Kuramoto's (1968) study has been the only serious effort. Much of the extensive work carried out by Krajina and his students (Krajina 1965; Brooke 1965; Peterson 1965; Archer 1963) in adjacent British Columbia is relevant, however. The following sketch is based on these sources, personal experience (Franklin and Trappe 1963), and unpublished data provided by Mr. George Douglas, University of Washington. For fuller accounts we recommend Brooke (1965), Kuramoto (1968), and Archer (1963).

Phyllodoce empetriformis-Cassiope mertensiana Communities

Ericaceous communities dominated by *Phyllodoce empetriformis* and *Cassiope mertensiana* are widespread in the Cascade Range and Olympic Mountains. *Vaccinium deliciosum* is a typical associate at lower elevations and may form communities in which it is the sole dominant (fig. 142). Other typical associates are *Luetkea pectinata, Polygonum bistortoides, Deschampsia atropurpurea, Hieracium gracile, Castilleja parviflora, Erigeron peregrinus, Polytrichum piliferum* and *Rhacomitrium sudeticum.* Alpine Podzols (O-A2-B2-C horizon sequence) or alpine rankers (O-A-C horizon sequence) are typically associated with *Phyllodoce-Cassiope* communities.

Valeriana sitchensis Communities

One of the lushest subalpine communities occurs on well-watered, but well-drained lower and middle slopes (fig. 143). This tall (about 1 m.), forby community is dominated by *Valeriana sitchensis* and a rich assemblage of associated plants such as *Veratrum viride, Polygonum bistortoides, Arnica latifolia, Lupinus latifolius, Carex spectabilis, Anemone occidentalis,* and *Potentilla flabellifolia.*

Figure 141. — **Although limited in distribution,** *Larix lyallii* **appears exceptionally well adapted to the timberline environment, often growing to higher elevation than any arborescent associates; this** *Larix* **is in fall coloration (Wenatchee National Forest, Washington).**

Luetkea pectinata Communities

Luetkea pectinata is characteristic of a highly variable group of communities found on stabilized talus, lithosolic slopes, and fellfields. These may be either hydric or relatively xeric sites. Many species may be associated with the *Luetkea* such as *Carex nigricans*, *Phyllodoce empetriformis*, *Cassiope mertensiana*, *Arnica latifolia*, *Lupinus latifolius*, *Deschampsia atropurpurea*, *Castilleja parviflora*, *Anemone occidentalis*, *Polygonum bistortoides*, *Valeriana sitchensis*, *Potentilla flabellifolia*, *Epilobium alpinum* var. *clavatum*, *Pogonatum alpinum*, and *Vaccinium deliciosum*.

Figure 142. — **A** *Vaccinium deliciosum-Phyllodoce empetriformis* **community typical of those found lower in the subalpine parklands of the Cascade Range.**

Figure 143. — *Veratrum viride*, **one of the major dominants in the lush** *Valeriana sitchensis* **communities found on well-watered parkland slopes in the northern Cascade Range.**

Carex spectabilis Community

Carex spectabilis, a relatively tall (up to 1 meter) *Carex*, sometimes dominates another meadow type found on relatively mesic lithosols and rock rubble. *Lupinus latifolius* is one of the more typical associates.

Snowbed Communities

Carex nigricans communities typify sites with a short growing season due to persisting snowbanks. *Carex nigricans* forms a thick dominant cover; typical associates are *Juncus drummondii*, *Antennaria alpina*, *Epilobium alpinum* var. *clavatum*, *Polytrichum norvegicum*, and *Polytrichadelphus lyallii*. *Saxifraga tolmiei* and bryophytes dominate rudimentary communities growing on sites having an even more prolonged snow cover. Typical constituents are *Gymnomitrium varians*, *Polytrichum norvegicum*, *Pohlia nutans*, *Saxifraga tolmiei*, *Polytrichum piliferum*, and *Andreaea nivalis*.

Streamside Communities

The communities found along streams are some of the showiest and most varied meadow types (fig. 144). *Mimulus lewisii*, *M. tilingii*, *Epilobium latifolium*, *E. alpinum* var. *clavatum*, *Leptarrhena pyrolifolia*, *Parnassia fimbriata*, *Caltha biflora*, *C. leptosepala*, *Juncus drummondii*, *Petasites frigidus* var. *nivalis*, *Philonotis fontana*, *Drepanocladus aduncus*, and *Erigeron peregrinus* are some characteristic species. At various locations in the Cascade Range, *Mimulus lewisii*, *Caltha* spp., *Leptarrhena*, or *Epilobium latifolium* may function as dominants. In the Olympic Mountains, *Saussurea americana* is a dominant. An *Eriophorum angustifolium-Sphagnum* spp.-*Carex aquatilis* community is characteristic of sites affected by a high water table the year around.

Other Community Types

There are many other kinds of subalpine communities. Grass-dominated communities occur generally on some of the warmer, drier slopes, particularly in rain-shadow areas; these

Figure 144. — *Mimulus lewisii-Epilobium latifolium* **community typical of the showy and varied meadow types found on riparian habitats in the subalpine parklands.**

are more characteristic of interior ranges and will be considered later. Communities of cushion plants occupy the dry, exposed ridges lacking winter snow accumulations. There are unique communities associated with the small groups of trees and krummholz. *Juniperus communis* typifies the varied communities found on exposed rock outcrops. *Athyrium alpestre* is characteristic of relatively unstable talus slopes.

HIGH CASCADES OF OREGON

Subalpine parklands in the central and southern Oregon Cascade Range appear considerably sparser than the densely vegetated regions just discussed. The High Cascades are the consequence of Pleistocene vulcanism, and the resulting substrates combined with a somewhat warmer and drier climate are important factors in the sparser vegetation. Pumice and cinder fields, outwash flats, and lava fields are common in timberline areas and provide extremely rigorous environments for plant growth.

Subalpine herbaceous communities have been studied on Three Sisters (VanVechten 1960) and near Mount Jefferson (Swedberg 1961). Lower in the zone, *Lupinus latifolius* meadows appear on moister sites and include *Castilleja parviflora*, *Potentilla flabellifolia*,

Epilobium alpinum, *Aster ledophyllus*, *Senecio triangularis* and *Ligusticum grayi* as constituents. On somewhat drier sites, *Trisetum canescens*, *Carex nigricans*, *Juncus drummondii*, and *Aster alpigenus* appear as dominants. Dry, south slopes are dominated by *Lupinus latifolius* or *Festuca viridula* or both. *Phyllodoce empetriformis*, *Cassiope mertensiana*, and *Vaccinium scoparium* are characteristic species on rockier sites and on cool north slopes, where they are joined by *Cardamine bellidifolia*, *Saxifraga tolmiei*, *Luetkea pectinata*, and *Castilleja* spp. This grouping and the *Carex nigricans-C. spectabilis* communities, associated with some wet meadows, are similar to subalpine communities previously discussed. *Phyllodoce* and *Cassiope* are also characteristic of ridges and slopes higher in the timberline region; VanVechten (1960) mentions *Luetkea pectinata*, *Castilleja parviflora*, *Hieracium gracile*, *Carex* spp., *Vaccinium scoparium*, and *Anemone occidentalis* among the associates.

Large, nearly barren pumice flats are conspicuous features of the subalpine parkland from Mount Jefferson south in the Cascade Range (VanVechten 1960; Swedberg 1961; Horn 1968). Typical colonizers are low compact perennials with large taproots. Characteristic species in the north are *Eriogonum marifolium*, *E. pyrolaefolium*, *Lupinus lepidus*, *Penstemon procerus*, *Raillardella argentea*, *Spraguea umbellata*, *Polygonum newberryi*, *Juncus drummondii*, *Aster alpigenus*, *Carex breweri*, *Castilleja arachnoidea*, and *Lomatium angustatum*. VanVechten (1960) studied one area (the Cinder Desert) on which *Eriogonum pyrolaefolium* was the only species of significance; occasional plants of *Spraguea umbellata*, *Draba aureola*, *Smelowskia calycina*, *Hulsea nana*, and *Carex breweri* were also present. Outwash flats apparently have similar poorly developed communities. VanVechten (1960) mentions *Eriogonum pyrolaefolium*, *E. marifolium*, *Raillardella argentea*, *Senecio fremontii*, *Spraguea umbellata*, and *Aster alpigenus* as characteristic species.

Horn's (1968) study of the Pumice Desert at Crater Lake National Park illustrates the sparsity of vegetation on these pumice and cinder flats. Coverage of all vascular plants totaled only 4.5 percent. *Eriogonum marifolium*, *Carex breweri*, *Stipa californica*, *Arenaria pumicola*, *Spraguea umbellata*, and *Polygonum newberryi* were the most important of 14 vascular species present on the desert. Horn (1968) conducted some environmental studies and concluded that a severe climatic regime (wide diurnal temperature fluctuations) and low soil fertility were responsible for the sparsity of the vegetation. Soil moisture was apparently available throughout the short, intense growing season.

INTERIOR MOUNTAINS

Grasslands are the dominant meadow types in many timberline areas of eastern Oregon and Washington (fig. 145). Included here are subalpine areas on the east side of the Washington Cascade Range and in the Wallowa and Blue Mountains.

A bunchgrass, *Festuca viridula*, characterizes pristine communities of this type (Pickford and Reid 1942) except in the Blue Mountains. Since we are considering a group of communities covering a wide geographic area, there are many associates. Some of these are:

Grasses and Grasslike: *Stipa lettermanii*, *S. columbiana*, *Agrostis rossae* (Cascade Range), *Carex geyeri*, *C. hoodii*, *Sitanion hystrix*, *Phleum alpinum*, *Agropyron* spp., *Bromus carinatus*, *Poa* spp. and *Trisetum spicatum*.

Forbs: *Eriogonum heracleoides*, *E. piperi*, *Gilia nuttallii*, *Lupinus leucophyllus*, *L. latifolius*, *Polemonium pulcherrimum*, *Penstemon rydbergii*, *Erigeron speciosus*, *E. salsuginosus*, *E. peregrinus*, *Arenaria formosa*, *Hieracium gracile*, *Potentilla glandulosa*, *Phlox diffusa*, *Polygonum phytolaccaefolium*, *P. newberryi*, and *P. bistortoides*.

Shrubs: *Artemisia tridentata* var. *vaseyana*, *Potentilla fruticosa*, *Ribes* spp., *Phyllodoce empetriformis*, and *Vaccinium scoparium* (all minor).

Most of the *Festuca viridula* grasslands have been grazed, many of them to excess, and are in some deteriorated grass-forb stage. In 1938, Pickford and Reid (1942) started a

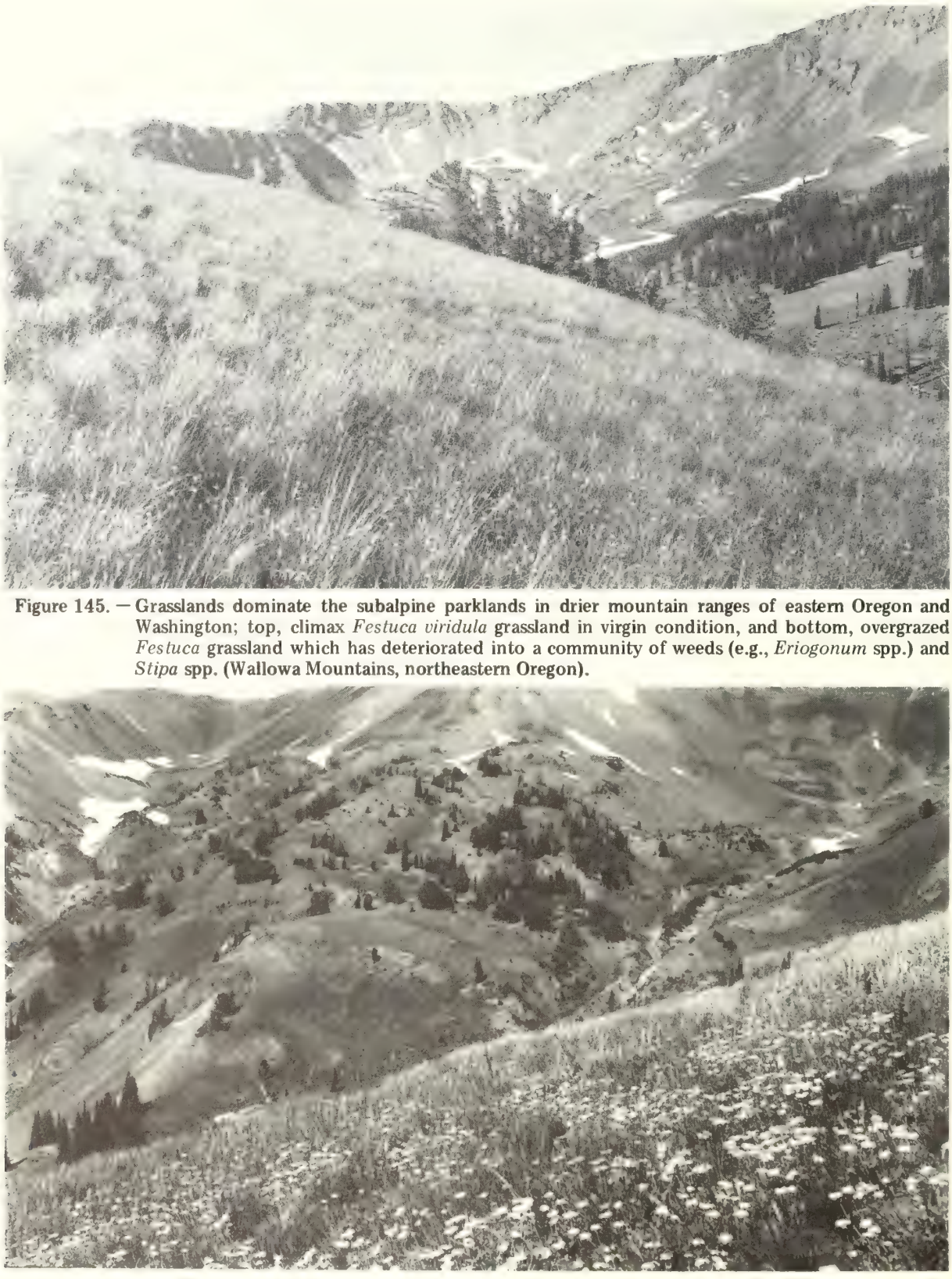


Figure 145. — Grasslands dominate the subalpine parklands in drier mountain ranges of eastern Oregon and Washington; top, climax *Festuca viridula* grassland in virgin condition, and bottom, overgrazed *Festuca* grassland which has deteriorated into a community of weeds (e.g., *Eriogonum* spp.) and *Stipa* spp. (Wallowa Mountains, northeastern Oregon).

study of changes in composition, productivity, and soil erosion associated with grazing of these types in the Wallowa Mountains. Recently, Strickler (1961) continued this study and made interesting photographic and analytic comparisons of conditions in 1938 and 1956-57. *Festuca viridula, Agropyron subsecundum, Melica bulbosa, Stipa lettermanii, S. columbiana* and *Lupinus leucophyllus* composed the virgin communities; total plant coverage was high. "Mixed grass-and-weed" and "weed-needlegrass" (*Stipa* spp.) communities with a high proportion of bare soil characterized the overgrazed sites. *Eriogonum* spp., *Gilia nuttallii, Penstemon rydbergii, Arenaria formosa, Artemisia tridentata,* and *Stipa* spp. were generally higher in these communities. Eventual return of these communities to their climax state (dominance of *Festuca viridula*) appears questionable.

Festuca-dominated meadows are often found on xeric subalpine habitats in the Olympic Mountains (Kuramoto 1968) and in the wetter parts of the Cascade Range. They are especially common in the rain shadows on the east and northeast slopes of the major volcanoes. *Festuca viridula-Lupinus latifolius* meadows dominate the Sunrise Ridge area on Mount Rainier, for example (fig. 146); a pumiceous soil may be partially responsible for extensive *Festuca*-meadow development there. The total community composition on these sites is somewhat altered from that on inland sites, but the overall physiognomy and dominant genera are the same.

Figure 146. — *Festuca viridula* meadows are also found in the rain shadows on the eastern slopes of the major volcanoes in the Cascade Range; *Festuca viridula-Lupinus latifolius* community on the northeastern slopes of Mount Rainier (Sunrise Ridge).

Dynamics in the Timberline Vegetation

Timberline areas are tension zones, dynamic ecotones, between tree and treeless regions. As at lower elevations, directional changes are constantly taking place in response to allogenic (e.g., long- and short-term climatic changes) and autogenic (changes in environment brought about by organisms) factors. Successional considerations are particularly complex in subalpine parkland since they involve relationships between tree species, various meadow communities, and forest and meadow communities.

Successional status is not often considered among timberline tree species since all are climax in a sense. None are in danger of elimination from the parkland since they can migrate to other open areas if more tolerant species become too competitive. Gradual changes do take place, however, and timberline tree species are displaced from sites they colonize. Franklin and Mitchell (1967) have described one successional sequence in development of subalpine tree groups near Mount Rainier; Douglas (1969) has described others. *Pinus albicaulis* or *Abies lasiocarpa* pioneer and are replaced in turn by *Tsuga mertensiana* and *Abies amabilis*. The pioneer species form the advancing outer fringe of the group. A succession of tree species may occur even in krummholz stands. Archer (1963), for example, suggested that a sequence of *Chamaecyparis nootkatensis, Abies lasiocarpa,* and, finally, *Tsuga mertensiana* may occur in krummholz stands at Garibaldi Park.

Successional relationships among the various meadow communities are not understood. Classically, they should involve development of hydric, xeric, and snowpatch communities

Figure 147. — Changes in the subalpine forest-meadow ecotones have typically been gradual; however, massive invasions of meadow areas by tree species have taken place in the last 50 years all over the Cascade and Olympic Mountains (Paradise Valley, Mount Rainier National Park).

toward a modal mesic type. Such changes may be extremely slow, however. Generally, the heather (*Phyllodoce-Cassiope*) and *Vaccinium deliciosum* communities are considered the higher levels of meadow successional series.

Changes in the forest-meadow ecotone have undoubtedly been of greatest interest. Gradual expansion of tree groups appears to have been taking place for many years between the forest and scrub lines except where fires produced temporary setbacks (Swedberg 1961; Franklin and Mitchell 1967). In the last half century, however, massive invasion of meadow areas has taken place at many locations in the Northwest (fig. 147) (Brink 1959; VanVechten 1960; Fonda 1967; Franklin 1966). These invasions are probably related to a short-term climatic fluctuation.

Changes in the overall elevation of forest line or scrub line have not been reported in this region with one exception — on Mount St. Helens. Mount St. Helens is a relatively

Figure 148. — Timberline is low (1,340 m.) but advancing on Mount St. Helens, a Cascade Range volcano of very recent origin (less than 2,000 years old).

low (2,948 m.) peak in southwestern Washington. The existing cone (fig. 148) is of very recent origin (less than 2,000 years ago) and its slopes are mantled with a coarse pumice. Timberline is very low compared with other peaks in the vicinity (about 1,340 m.) and composed of species not normally found at timberline — *Pinus contorta* (dominant), *P. monticola*, *Pseudotsuga menziesii*, *Populus trichocarpa*, *Abies procera*, and *Tsuga heterophylla*, for example. Lawrence (1938) concluded that timberline is advancing at a discernible rate on Mount St. Helens after studying some photographs taken in 1897 and suggests present timberline is a consequence of edaphic conditions.

Alpine Communities

Very little is known about the communities found in true alpine environments near and above the scrub line or krummholz limits. Habitats capable of supporting developed alpine plant communities are not extensive in Oregon and Washington in contrast to the large alpine acreages in the Rocky Mountains. Most of the Alpine Zone is steep and rugged, occupied by glaciers, snowfields, bare rock, and rubble (fig. 149). And much of it occurs on only recently dormant Pleistocene volcanoes. Troll (1955) noted the narrow elevational band between timberline and permanent snowline on Mount Rainier.

Many of the meadow communities characteristic of the subalpine parkland do extend into at least the lower reaches of the Alpine Zone, although they may be somewhat modified in form and composition. *Phyllodoce empetriformis-Cassiope mertensiana*, *Valeriana sitchensis*, *Carex nigricans*, and *Luetkea pectinata* communities are examples. Krajina (1965) feels the *Phyllodoce-Cassiope* association is the climatic climax in the Alpine Zone of adjacent British Columbia. Scott (1962) lists Saxifrage-Heather association as climax in western Washington's Arctic-Alpine Zone; this zone is considered to lie between 2,300 and 2,600 meters with essentially no vegetation above that level.

In the absence of data on communities, the best we can do is to indicate some species typical of the Alpine Zone. On Mount Rainier

Figure 149. — The Alpine Zone is not well developed in Oregon and Washington; areas above timberline are occupied primarily by glaciers, snowfields, bare rock, and rubble (Mount Rainier from Sunrise Ridge).

these include *Eriogonum pyrolaefolium*, *Saxifraga tolmiei*, *Spraguea umbellata*, *Silene acaulis*, *Draba aureola*, *Smelowskia ovalis*, *Lupinus lepidus*, *Polemonium pulcherrimum*, *Castilleja angustifolia*, *Erigeron aureus*, *Dryas octopetala*, *Oxyria digyna*, *Salix nivalis*, and many Gramineae, *Carex*, and Juncaceae (Jones 1938). On Three Sisters, typical alpine plants are *Hulsea nana*, *Draba aureola*, *Claytonia megarhiza*, *Polemonium elegans*, *Phacelia hastata*, *Trisetum spicatum*, *Poa pringlei*, *Carex breweri*, and *Oxyria digyna* (VanVechten 1960).

SITUATIONS OF SPECIAL INTEREST

There are many habitats supporting unusual floras or communities which are of particular interest to the geneticist, ecologist, or plant geographer. These may be the result of unusual substrates (e.g., serpentine) or of unique topographic features. Sufficient data are available to consider three such areas: (1) areas of recent vulcanism, (2) serpentine tracts, and (3) the Columbia Gorge.

Table 28. — Representative species in three plant associations on lava flows near Santiam Pass, Oregon

Item	*Aceretum circinati lavosum*	*Pseudotsugeto-abietum lasiocarpae*	*Pseudotsugetum-abietum grandis*
Substrate	Block basalt	Block basalt with smaller size scoria in broken crust	Grayer, rounded block basalts with high proportion sand and ash
Trees		*Pseudotsuga menziesii, Abies lasiocarpa*	*Pseudotsuga menziesii, Abies grandis, Pinus contorta, P. monticola*
Shrubs	*Acer circinatum, Rhamnus purshiana, Holodiscus glabrescens, Arctostaphylos columbiana*	*Acer circinatum, Arctostaphylos nevadensis, A. columbiana, Castanopsis chrysophylla, Pachistima myrsinites*	*Castanopsis chrysophylla, Pachistima myrsinites, Acer circinatum, Rubus parviflorus, Ceanothus velutinus*
Herbs	*Cryptogramma acrostichoides, Penstemon menziesii davidsonii, Sedum oregonense, Juncus parryii*	*Sedum oregonense, Penstemon menziesii davidsonii, Chimaphila umbellata occidentalis*	*Chimaphila umbellata occidentalis, Linnaea borealis, Festuca occidentalis, Xerophyllum tenax, Penstemon cardwellii*
Mosses	*Rhacomitrium patens, R. lanuginosum, Dicranum scoparium, Hypnum fertile*	*Rhacomitrium patens, R. lanuginosum, Dicranum scoparium, Hypnum fertile*	*Rhacomitrium patens, R. lanuginosum, Dicranum scoparium, Hypnum fertile, Aulacomnium androgynum, Rhytidiadelphus triquetrus, Polytrichum juniperinum*

Source: Roach (1952).

Areas of Recent Vulcanism

The eruption and deposition of volcanic materials has been taking place in the Northwest up into recent times, particularly in the Cascade Range. Mount Lassen (in California) erupted early in this century and Mount St. Helens was last active about the middle of the 19th century. This activity has resulted in frequent occurrence of cinder cones, pumice and ash fields, lava flows, and laharic deposits[30] which support communities quite unlike those found on adjacent habitats. Some of these have been discussed in preceding sections, but at this time we would like to consider lava flow and mudflow communities in detail.

LAVA FLOWS AND LAVA-DAM LAKES

Pleistocene-Recent lava flows are conspicuous at many places in the Cascade Range; e.g., in central Oregon (Peterson and Groh 1966), the Santiam and McKenzie Pass areas (Taylor 1968) in the Oregon Cascade Range, and in the vicinity of Mount St. Helens and Mount Adams, Washington Cascade Range. These lava fields provide a rugged environment for pioneer plant communities, yet they are often surprisingly rich floristically, particularly in cryptogams.

The most extensive study of lava flow communities was conducted by Roach (1952) on the Nash Crater lava flows near Santiam Pass, Oregon. He recognized three associations which represented a series in development of substrate and community density and organization: the *Aceretum circinati lavosum*, *Pseudotsugeto-abietum lasiocarpae*, and *Pseudotsugetum-abietum grandis* associations. The major species found in these associations are listed in table 28. All of these associations are edaphic climaxes in which *Acer circinatum*, *Pseudotsuga menziesii* and *Abies lasiocarpa*, and *Pseudotsuga menziesii* are the respective dominants.

[30] "The term, lahar, includes all of the broad textural range of debris flows and mudflows of volcanic origin . . . any unsorted or poorly sorted deposit of volcanic debris that moved and was deposited as a mass and owed its mobility to water." (Mullineaux and Crandell 1962).

Some studies have also been made of the basaltic flows found in southern Washington (Franklin 1966; Franklin and Mitchell 1967). On one flow (near Wind River), a *Pseudotsuga menziesii-Abies lasiocarpa-Acer circinatum* community, very similar to the one described by Roach (1952), is present. The Wind River and Nash Crater flows lie almost entirely within the *Abies amabilis* Zone, however. Near Mount Adams is a large flow (Big Lava Beds) which extends from about 520 to 1,100 meters in elevation. Communities vary from *Pseudotsuga menziesii-Quercus garryana* at the lowest through *Pinus contorta/Arctostaphylos uva-ursi* to *Abies lasiocarpa/Xerophyllum tenax* (fig. 150) at the highest elevations (Franklin 1966). All of these communities are very rich in mosses and lichens and there are many vascular species present in niches and crevices, surprising in view of the xeric, sterile appearance of the substrate. Dis-

Figure 150. — An *Abies lasiocarpa/Xerophyllum tenax* community is found at about 1,200-meter elevation on the Big Lava Beds near Mount Adams (Gifford Pinchot National Forest, Washington).

Figure 151. — Lava flows have created lakes with widely fluctuating water levels by blocking stream drainages; Cottonwood, Sedge, and Fontinalis Zones were conspicuous around Goose Lake, an impoundment of this type (Gifford Pinchot National Forest, Washington).

cussion of *Pinus contorta* community will be deferred, since it is similar to many found on lahars and glacial outwash elsewhere.

Lava flows frequently blocked drainages of many small streams, and seasonal lakes or lakes with widely fluctuating water levels are not uncommon. Kienholz (1931) studied one of the latter type adjacent to Big Lava Beds (southern Washington). He recognized five zones around Goose Lake (fig. 151): Willow-Alder (*Salix sitchensis-Alnus rubra*); Sedge (*Carex* spp.); Fontinalis (*Fontinalis antipyretica gigantea*); Cottonwood (*Populus trichocarpa*); and Weed (*Artemisia tilesii-Stachys cooleyae-Scrophularia lanceolata*).

More frequently, lava-dammed lakes are filled during the winter months when underground drainage systems are inadequate and drain completely during the summer. Roach (1952) describes one of these which is covered primarily by a bog type vegetation dominated by *Carex sitchensis* and *Vaccinium occidentale*. In nearby Fish Lake where the substrate is thin and rocky, a dense nearly pure community of *Carex aperta* and *C. rostrata* 1 meter or more in height develops during the short growing season.

MUDFLOWS

Lahars, including mud and debris flows as defined earlier, are common near the major volcanoes in the Cascade Range (Mullineaux and Crandell 1962; Tidball 1965; Crandell and Mullineaux 1967). Some of these are occupied by communities relatively normal in composition for the zone in which they occur (Franklin 1966). Others are sufficiently recent that they are obvious sites for studies of vegetation succession and soil development, such as some at Mount Rainier (Frehner 1957; Ballard 1963), Mount Lassen (Bailey 1963), and Mount Shasta (Dickson and Crocker 1953a, 1953b, 1954). Still others in the *Tsuga heterophylla* and *Abies amabilis*

Figure 152. — Mudflows are common features near the major volcanoes in the Cascade Range; the Kautz Creek mudflow occurred in 1947, burying and killing the original forest (*photo courtesy Mount Rainier National Park*).

Zones are occupied by climax stands of *Pinus contorta* (Franklin 1966). The status of the vegetation appears to be primarily a function of age and nature of the substrate.

Frehner's (1957) study of succession on the 1947 Kautz Creek mudflow (fig. 152) at Mount Rainier has shown that many conifers, typical of adjacent zonal forests, will invade recent mudflows. *Populus trichocarpa*, *Salix* spp., and *Alnus rubra* have been major pioneer species, however, and *Alnus rubra* had special importance as a consequence of its nitrogen-fixing abilities. Occurrence of standing snags appeared to be an important factor in the composition of the pioneering vegetation.

A *Pinus contorta/Arctostaphylos* community is found on some xeric laharic deposits (fig. 153), lava flows, and coarse glacial outwash in southwestern Washington and northwestern Oregon (Franklin 1966; Stephens 1966). This appears to be a stable climax type on such habitats in many areas, although occasional specimens of more tolerant tree species such as *Pseudotsuga menziesii*, *Tsuga heterophylla*, or *Abies lasiocarpa* may be present; droughty years can eliminate many of these. In other cases, it is clearly successional to a *Pseudotsuga menziesii*, *P. menziesii-Pinus contorta*, or *Tsuga heterophylla* community. Although details of composition vary, the dominance of *Pinus contorta* and either *Arctostaphylos nevadensis* or *A. uva-ursi* in their respective layers (fig. 153) and a rich cryptogammic ground cover are distinguishing. Typical cryptogams are: *Rhacomitrium canescens* var. *ericoides*, *Cladonia grayii*, *Polytrichum juniperinum*, *Cladonia bellidiflora*, *C. ecmocyna* vars. *ecmocyna* and *intermedia*, *Stereocaulon paschale*, *Cladonia phyllophora*, *C. rangifera*, *Polytrichum piliferum*, *Cladonia coniocraea*, *Lecidea quadricolor*, *Cladonia macrophylloides*, *Rhacomitrium heterostichum*, *R. sudeticum*, and *Aulocomnium androgynum*.

Figure 153. — *Pinus contorta/Arctostaphylos* communities are widespread on mudflows, glacial outwash, and lava flows in the Cascade Range of southern Washington and northern Oregon; this community is distinguished by a depauperate understory of *Arctostaphylos uva-ursi* or *A. nevadensis* and many species of lichens and mosses (Kalama River lahar, Gifford Pinchot National Forest, Washington).

Figure 154. — Vegetations on serpentine sites and adjacent nonserpentine soils often contrast sharply; in this Siskiyou Mountain area, open *Pinus jeffreyi* stands on serpentine (right) contrast with those of *Pseudotsuga menziesii, Pinus lambertiana,* and *Libocedrus decurrens* on nonserpentine soils (left).

Serpentine Areas

Serpentine areas are characterized by unusual plant communities and floras. Vegetation is invariably stunted on serpentine sites in comparison with that on adjacent nonserpentine soils. Sharp contrasts in physiognomy, composition, and productivity of communities are typical at margins of serpentine outcrops (fig. 154). The floras are unusual including endemics restricted to serpentine species not usually found in adjacent communities and "bodenvag" species which appear edaphically indifferent (Kruckeberg 1954, 1964, 1967; Whittaker 1954b, 1960; Waring 1969).

Serpentine areas in this discussion refer to habitats with soils derived from ultramafic rocks either as peridotite and dunite (igneous forms) or as serpentinite (the metamorphic derivative) (Kruckeberg 1967). Such soils are typically low in total and adsorbed calcium and high in magnesium, chromium, and nickel (Walker 1954). Walker (1954) has analyzed the factors affecting plant growth on such sites and concluded the plants growing there must be tolerant of low calcium levels and one or more additional conditions; e.g., high nickel, chromium, or magnesium and physically unfavorable shallow soils.

There are three major serpentine areas in the Pacific Northwest (Whittaker 1954a; Kruckeberg 1964, 1967): (1) a large area in the Siskiyou Mountains of Oregon; (2) about 100 square miles in the Wenatchee Mountains, an eastern outlier of the Cascade Range; and (3) about 30 square miles in northwestern Washington near Mount Baker (Twin Sisters Mountain) and in parts of the San Juan Islands. Serpentine communities have been most thoroughly analyzed in the Siskiyou Mountains (Whittaker 1954b, 1960; Waring 1969) but Kruckeberg (1964, 1967) has provided general descriptions for the Washington serpentines.

SISKIYOU MOUNTAINS

Perhaps the outstanding feature of the Siskiyou serpentines is the *Pinus jeffreyi*/grass woodland which occupies the most xeric ser-

Figure 155. — Ultramafic rock outcrops in Washington typically consist of open woodlands and barren slopes; left, landscape mosaic on ultramafic slopes and, right, local outcrop of serpentine showing the extremely barren openings (Teanaway River drainage, Wenatchee National Forest; *photos courtesy A. R. Kruckeberg*).

pentine sites from 300- to 2,000-meter elevation (Whittaker 1960; Waring 1969). *Pinus jeffreyi* is typically the only tree species present in these open woodlands (fig. 154) along with a rather sparse growth of grasses (e.g., *Stipa lemmoni*, *Sitanion jubatum*, *Melica geyeri*, *Elymus glaucus*, and *Festuca ovina*) and occasional *Arctostaphylos viscida*. Forests, intermediate in elevation and moisture regime, are typified by a sparse and xerophytic appearance and dominated by a mixture of several conifers — *Pseudotsuga menziesii*, *Libocedrus decurrens*, *Pinus jeffreyi*, *P. monticola*, *P. lambertiana*, and *P. attenuata* (Whittaker 1960). Associated with them is a dense layer of sclerophyllous shrubs such as *Quercus vaccinifolia*, *Lithocarpus densiflora*, *Vaccinium parvifolium*, *Garrya buxifolia*, and *Umbellularia californica*. Herb coverage is generally low but rich in species. Whittaker (1954b, 1960) has commented at length on the "two-phase" or patchwise distribution of the shrub cover in these forests with essentially closed shrub patches alternating with herbaceous openings. On more mesic sites the shrubs form the matrix, but on more xeric sites the herbaceous openings are dominant.

Other community types described on Siskiyou serpentines include: *Chamaecyparis lawsoniana-Pinus monticola-Pseudotsuga menziesii* stands, with a dense shrubby understory in ravines and draws, and higher elevation forests dominated by *Abies concolor* and *Pseudotsuga menziesii* and *Pinus monticola*, singly or collectively, over a *Xerophyllum tenax* and *Arctostaphylos nevadensis* understory.

Whittaker (1960) has provided a list of more useful serpentine indicator plants in the Siskiyou area. These include: (1) some dominants — *Pinus jeffreyi*, *P. monticola*, *P. attenuata*, *Quercus chrysolepis*, *Ceanothus cuneatus*, and *Arctostaphylos nevadensis;* and (2) species which are of more frequent occurrence on smaller serpentine areas — *Galium ambiguum*, *Pyrola dentata*, *Lomatium macrocarpum*, *Cheilanthes siliquosa*, *Rhododendron macrophyllum*, and *Darlingtonia californica*. *Xerophyllum tenax* is considered the most useful single indicator of small serpentine outcrops.

WASHINGTON SERPENTINES

Most ultramafic outcrops in Washington occur within forested zones, and communities consist of open woodland with barren slopes between the scattered stunted trees (fig. 155) (Kruckeberg 1964, 1967). In the Wenatchee

Figure 156. — The Columbia Gorge, the only nearly sea level break in the Cascade Range in Oregon and Washington and a major route for plant and animal migration between the western and eastern halves of these States; Beacon Rock, a large monolith, is visible (left center) in this east-facing view through the center of the Gorge.

Mountains, *Pseudotsuga menziesii*, *Pinus contorta*, and *Pinus monticola* are typical tree species at lower elevations and *Abies lasiocarpa* and *Pinus albicaulis* at higher elevations. *Juniperus communis* and *Arctostaphylos nevadensis* are typical shrubs. Herbs are found in serpentine openings, talus, etc., such as *Agropyron spicatum*, *Festuca viridula*, *Poa curtifolia*,* *Eriogonum pyrolaefolium*,* *E. compositum*, *Silene parryi*, *Thlaspi alpestre*,* *Anemone drummondii*,* *Phlox diffusa*, *Arenaria obtusiloba*,* *Claytonia nivalis*,* *Lomatium cuspidatum*,* *Douglasia nivalis*,* *Achillea millefolium* var. *lanulosa*, *Senecio pauperculus*, *Cheilanthes siliquosa*,* and *Polystichum mohrioides* var. *lemmonii*.* Those species with asterisks (*) Kruckeberg[31] considers serpentine indicator or character species.

[31] Kruckeberg, Arthur R. 1964. Plant life on serpentines and other ultramafic rocks in northwestern North America. 13 pp., mimeo. (from talk given at X Int. Bot. Congr., Edinburgh, Scotland).

Serpentine areas in northwestern Washington have similarly sparse, open vegetation and an abundance of barren rock (Kruckeberg 1964, 1967). *Pinus contorta*, *Pseudotsuga menziesii*, *Rhacomitium canescens* var. *ericoides*, and *Cheilanthes siliquosa* seem to be characteristic on Twin Sisters Mountain. Stunted *Pseudotsuga menziesii*, *Pinus contorta*, *Juniperus scopulorum*, and *Arbutus menziesii*, along with dense herbaceous layers, are found on some of the San Juan serpentines.

The Columbia Gorge

The Columbia Gorge is an unusual physiographic feature which is of considerable importance to biologists (fig. 156). The Columbia River cut this nearly sea level route directly across the axis of the Cascade Range. As Detling (1966) pointed out, this is the only point between the Fraser River (in British Columbia) and Klamath River (in California) where a feature of this type is found. It has provided a major route for both plant and animal migration between the western and eastern halves of Washington and Oregon (Detling 1961, 1966, 1968). At the same time, it contains many species which are endemics or constitute relict populations.

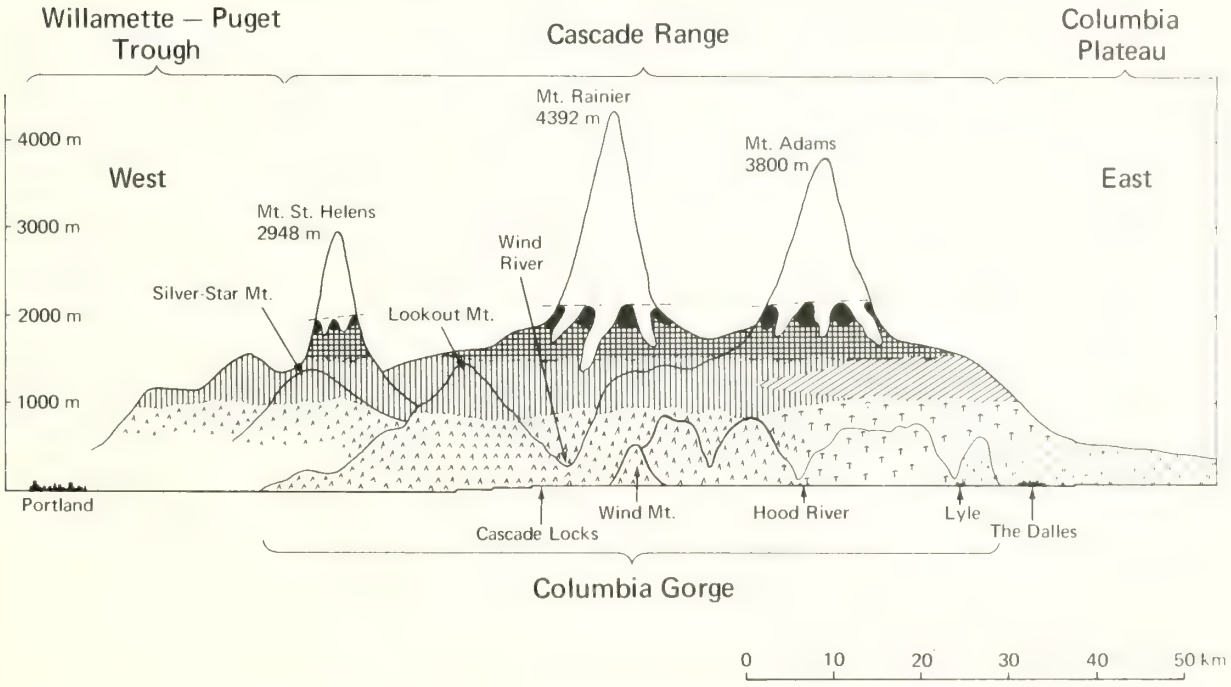
The weather of the Columbia Gorge is as unique as its topography (Lynott 1966), since it provides a sea level transition from marine to continental climate in a region where they are otherwise separated by major mountain barriers. Strong winds are a dominant feature. During the winter, low-pressure systems move through the gorge on westerly winds, bringing heavy rains as a consequence of streamline convergence. Strong high-pressure systems east of the Cascade Range can bring gale-force easterly winds through the gorge, resulting in extremely hot dry weather during summer and fall and cold continental air during the winter. Marine low-pressure systems and this cold air may collide, particularly in the west end of the gorge, with blizzards, ice storms, and freezing rain the result.

These climatic features have profound effects upon the vegetation as Lawrence (1939) and Troll (1955) have pointed out. Tree crowns are markedly deformed or one-sided. In the east end of the gorge, they are flagged toward the east by the dominantly westerly winds. This is the result of wind training, not

breakage. At the west end of the gorge, trees typically lack branches on the easterly sides of the stem. This deformation is the result of branch breakage during the severe ice storms and destruction of buds and branches by dry east winds.

Another interesting ecological feature of the gorge is the opportunity it provides to study the transition from xerophytic *Pinus ponderosa-Quercus garryana* forests on the east to the mesophytic *Pseudotsuga menziesii-Tsuga heterophylla* types on the west. Troll (1955) has provided an interesting vegetation profile (fig. 157) indicating the distribution and interdigitation of the various zones through this area.

Figure 157. — Vegetation profile through the Columbia Gorge and Cascade Range (from Troll 1955).



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APPENDIX

BRIEF DESCRIPTION OF GREAT SOIL GROUPS

Descriptions follow those contained in "Soils of the Western United States" (Western Land Grant Universities et al. 1964). Soil horizon thickness classes are approximately: (1) very thin, less than 3 cm.; (2) thin, 3 to 10 cm.; (3) moderately thick, 10 to 20 cm.; (4) thick, 20 to 40 cm.; and (5) very thick, over 40 cm. All other classes and designations follow the "Soil Survey Manual" and supplement (U.S. Soil Conservation Service 1951, 1962).

Azonal Soils

Alluvial

Alluvial soils are formed on recent alluvium and, therefore, exhibit very little profile development. A horizons are thin to moderately thick, light to dark in color, with low to moderate amounts of organic matter accumulation. B horizons are lacking, while the C is made up of stratified alluvium which is often stony or gravelly. Soil reaction ranges from moderately alkaline to medium acid.

Lithosols

Lithosols are well drained, shallow, generally stony soils over bedrock. A horizons are very thin to moderately thick, light to dark in color, with low to moderate amounts of incorporated organic matter. B horizons are lacking; a transitional AC horizon may be present. Soil reaction may vary from moderately alkaline to medium acid.

Regosols

Regosols are well to excessively drained, poorly developed soils formed in deep, unconsolidated materials. A horizons are very thin to moderately thick, light to dark colored, with low to moderate organic matter content. B horizons are lacking, and the C is made up of uniform or stratified material. Reaction ranges from slightly acid to moderately alkaline. In dry areas, the soil may be calcareous.

Zonal Soils

Alpine Turf

Alpine Turf soils are formed under alpine grasses and herbs in high mountain areas having a cold, humid climate. These well to imperfectly drained soils have thin to thick black A horizons of moderate to high organic matter content. B horizons are lighter colored, generally stony, and may have noticeable increase in clay. The stony or gravelly C horizon may be layered by solifluction processes. Soil reaction is strongly acid in the surface and medium acid in the B.

Brown

Brown soils are formed under shrub-steppe in cool, semiarid climates. These well-drained soils have moderately thick, dark-brown A horizons of low organic matter content. B horizons typically have more clay and subangular blocky to prismatic structure. Soil reaction is slightly alkaline in the surface, and alkalinity increases with depth. A zone of calcium carbonate accumulation is generally present as a Bca or Cca horizon.

Brown Podzolic

Brown Podzolic soils are formed under forest in cool, humid climates. Soil drainage varies from well to imperfectly drained. 01 and 02 horizons are usually present. The A1 horizon is thin and dark grayish-brown in color. A very thin, intermittent A2 horizon may also be present. The brown-colored B horizon gives evidence of iron and humus accumulation but has no appreciable clay increase. Soil reaction is medium to strongly acid.

Chernozem

Chernozem soils are formed under steppe or shrub-steppe in cool, subhumid climates. These moderately well to well drained soils have moderately thick, very dark-brown to black A horizons of moderate organic matter content. B horizons usually contain more clay than the A, but may be distinguished solely on the basis of color and structural changes. Soil reaction becomes more alkaline with depth, and a zone of carbonate accumulation is generally present in the lower part of the B.

Chestnut

Chestnut soils are formed under steppe or shrub-steppe in cool, semiarid climates. These well-drained soils have dark-brown, moderately thick A horizons containing moderate amounts of organic matter. B horizons often contain more clay than the A but may be distinguished largely by color and structural changes. Structure in the B may be blocky, subangular blocky, or prismatic. Soil reaction becomes more alkaline with depth, and a zone of carbonate accumulation usually occurs in or below the B horizon.

Desert

Desert soils are formed under shrub-steppe in warm, arid climates. These well-drained soils have thin, light-colored A horizons of low organic matter content. Structure of the A is platy. B horizons typically show increased clay content and are as dark or darker colored than the A1. Reaction varies from neutral to strongly alkaline. Horizons of calcium enrichment, sometimes cemented with lime or silica, occur in or below the B horizon.

Gray-Brown Podzolic

Gray-Brown Podzolic soils are formed under forest in cool to cold, subhumid climates. They are well to imperfectly drained. A1 horizons are thin to moderately thick and very dark gray. A thin, light-colored A2 horizon occurs beneath the A1. B horizons contain more clay than the A2 and have darker colors. Structure is blocky, subangular blocky, or prismatic. Reaction is medium acid in the surface and medium to slightly acid in the B horizon.

Gray Wooded

Gray Wooded soils are formed under forest in cold, subhumid climates. They are well to imperfectly drained. Thin to moderately thick 01 and 02 horizons are present at the soil surface. A thin A1 horizon is generally present. The A2 horizon is light colored, low in organic matter content, and has platy structure. The B horizon contains more clay than the A2 and has blocky or subangular blocky structure. Surface reaction is slight to medium acid and may approach neutrality with depth.

Noncalcic Brown

Noncalcic Brown soils are formed under shrub communities (e.g., chaparral) in warm, subhumid climates. These well to moderately well drained soils have moderately thick to very thick, brown or reddish-brown, massive A horizons of low organic matter content. B horizons contain more clay and are redder than the A. They may be massive or have blocky or prismatic structure. Hard layers caused by silica cementation commonly occur in the B. In addition, small amounts of carbonate may be present in the lower part of the B horizon.

Podzol

Podzol soils are formed under forest in cool to cold, subhumid climates. They are well to moderately well drained. Thin to thick (5 to 40 cm.) 01 horizons overlie thin to thick (5 to 25 cm.) 02 horizons. A2 (bleicherde) horizons are thin to thick, white to very pale brown, and very low in organic matter content. B horizons are much darker and contain accumulations of iron and humus. Structure ranges from very weak blocky to strong blocky or prismatic. Soil reaction is strongly to very strongly acid.

Prairie

Prairie soils are formed under grassland vegetation in cool, subhumid to humid climates. These well to imperfectly drained soils have thick, very dark A horizons generally containing large amounts of organic matter. B horizons typically have more clay but may be differentiated from the A largely by color and structural changes. Prairie soils exhibit decreasing acidity with depth, and accumulations of calcium carbonate may occur in the C horizon.

Reddish Brown Lateritic

Reddish Brown Lateritic soils are formed under forest in warm, humid climates. They are moderately well to well drained. A horizons are moderately thick, reddish brown, and of granular structure. Shotlike iron-magnesium concretions are commonly present. B horizons are red or reddish brown and have more clay than the A. Structure is typically moderate blocky or subangular blocky. Reaction varies from moderately to very strongly acid.

Sierozem

Sierozem soils are formed under shrub-steppe in cool, arid climates. These well-drained soils have thin, light-colored A horizons containing low amounts of organic matter. Soil structure is typically platy, especially in the upper portion. B horizons contain more clay and are often darker than the A. Calcium carbonate accumulations, often cemented, generally occur in the lower part of, or just below, the B horizon. Soil reaction ranges from mildly to strongly alkaline.

Sols Bruns Acides

Sols Bruns Acides soils are formed under coniferous forest vegetation in cool, humid climates. Soil drainage may vary from well to imperfectly drained. Thin 01 and 02 horizons are usually present at the soil surface. A horizons are thick, dark brown to dark reddish brown, and moderate to high in organic matter content. B horizons show no evidence of illuviated clay and are distinguished by color and structure (subangular blocky). Soil acidity generally increases with depth and ranges from medium to very strongly acid.

Western Brown Forest

Western Brown Forest soils are formed under forest in areas of forest-steppe transition and cool, semiarid to subhumid climates. These well or moderately well drained soils have moderately thick, dark-colored granular A horizons containing low to moderate amounts of organic matter. B horizons may show increased clay content but are usually distinguished by color and structural changes. Typical B horizon structure is subangular blocky. Reaction varies from slight to medium acid, and acidity commonly decreases with depth. A zone of calcium carbonate accumulation occurs in the lower B or upper C horizon.

Intrazonal Soils

Alpine Meadow

Alpine Meadow soils are formed under high-elevation meadows in cold to very cold and humid climates. These soils are imperfectly to poorly drained. The A1 horizon is thick, very dark brown to black, moderate to high in organic matter content, and frequently stony. B horizons are lacking. C horizons are stony, mottled, and gleyed. Soil reaction is strongly or very strongly acid.

Grumusols

Grumusols occur under grassland or grass-shrub vegetation in a variety of climatic zones. They are generally well drained except in depressional areas. A horizons are very thick, dark colored, and contain low to moderate amounts of organic matter. Montmorillonitic clay content is usually high. B horizons are lacking. C horizons have wide vertical cracks which typically extend up into the A

horizon. Carbonate accumulation may occur in the lower A or upper C horizon. Reaction varies from slightly acid to slightly alkaline.

Humic Gley

Humic Gley soils occur under meadows in virtually all climatic zones. They are poorly to very poorly drained. The A horizon is very dark colored and contains large amounts of organic matter. The B horizon is gleyed or mottled and is higher in clay content. Soluble salts may be present in weak to moderate concentrations. Soil reaction ranges from moderately alkaline to strongly acid.

Planosol

Planosols may occur under steppe, shrub-steppe, or forest and in a wide variety of climatic zones. They are imperfectly to poorly drained. A1 horizons are thick, dark colored, with moderate to high organic matter content. An A2 horizon of variable thickness underlies the A1; it is massive and mottled. B horizons contain appreciably more clay and have blocky or prismatic structure. A cemented layer may be present in the lower solum. Reaction varies from medium to mildly alkaline.

Solonchak

Solonchak soils occur under shrub-steppe in arid to semiarid areas. These poorly drained soils have thin, light-colored A horizons low in organic matter content. Salt crusts are commonly present on the surface. B horizons are lacking.

Solonetz

Solonetz soils occur under steppe or shrub-steppe in arid to semiarid areas. Soil drainage ranges from well to imperfectly drained. A horizons are thin, platy, light colored, and contain low amounts of organic matter. B horizons contain more clay and have blocky, prismatic, or columnar structure. Portions of the B horizon contain more than 15 percent of exchangeable sodium. A zone of carbonate enrichment, commonly cemented, occurs in the lower part of or below the B horizon. Soil reaction varies from neutral to very strongly alkaline.

Miscellaneous Land Type

Rockland

Rockland designates areas with only sparse vegetation, dominated by rock outcrops, rock rubble, boulders, or stones. Restricted areas of thin soils may be included, but in general, soil development is severely limited.

LIST OF PLANT SPECIES

The major sources for the scientific names of these species are Little (1953) for trees and a few shrubs, Hitchcock et al. (1955, 1959, 1961, 1964) for Dicotyledonae, and Peck (1961) for the remaining vascular plants. Mosses follow Lawton (1965) and lichens follow Howard (1950) in most cases. Common names are according to Little (1953), Garrison, Skovlin, and Poulton (1967) and Peck (1961). Mosses, lichens, and liverworts are marked with an asterisk; no common names are given for these species.

Abies amabilis (Dougl.) Forbes	Pacific silver fir
Abies concolor (Gord. & Glend.) Lindl.	White fir
Abies grandis (Dougl.) Lindl.	Grand fir
Abies lasiocarpa (Hook.) Nutt.	Subalpine fir

Abies magnifica Murr. var. *shastensis* Lemm.	Shasta red fir
Abies procera Rehd.	Noble fir
Abronia latifolia Eschsch.	Yellow sandverbena
Acer circinatum Pursh	Vine maple
Acer glabrum Torr.	Rocky Mountain maple
Acer glabrum var. *douglasii* (Hook.) Dipp.	Rocky Mountain maple
Acer macrophyllum Pursh	Bigleaf maple
Achillea millefolium L.	Western yarrow
Achillea millefolium var. *lanulosa* Piper	Western yarrow
Achlys triphylla (Smith) DC.	Deerfoot vanillaleaf
Actaea rubra (Ait.) Willd.	Baneberry
Adenocaulon bicolor Hook.	Trail plant
Agoseris heterophylla (Nutt.) Greene	Annual agoseris
Agoseris hirsuta (Hook.) Greene	Woolly agoseris
Agropyron dasystachyum (Hook.) Scribn.	Thickspike wheatgrass
Agropyron spicatum (Pursh) Scribn. & Sm.	Bluebunch wheatgrass
Agropyron subsecundum (Link) Hitchc.	Bearded wheatgrass
Agropyron trachycaulum (Link) Malte.	Slender wheatgrass
Agrostis hallii Vasey	Halls bentgrass
Agrostis rossae Vasey	Ross bentgrass
Agrostis tenuis Sibth.	Colonial bentgrass
Aira caryophyllea L.	Silver hairgrass
Aira praecox L.	Early hairgrass
Alnus rhombifolia Nutt.	White alder
Alnus rubra Bong.	Red alder
Alnus sinuata (Reg.) Rydb.	Sitka alder
Aloina rigida (Hedw.) Limpr.*	
Amelanchier alnifolia Nutt.	Saskatoon serviceberry
Amelanchier pallida Greene	Pale serviceberry
Ammophila arenaria (L.) Link	European beachgrass
Anaphalis margaritacea (L.) B. & H.	Pearly everlasting
Andreaea nivalis Hook.*	
Anemone deltoidea Hook.	Threeleaf anemone
Anemone drummondii Wats.	Drummond anemone
Anemone lyallii Britt.	Lyall anemone
Anemone occidentalis Wats.	Western pasqueflower
Anemone oregana Gray	Oregon anemone
Anemone piperi Britt.	Piper anemone
Angelica lucida L.	Sea-watch
Antennaria alpina (L.) Gaertn.	Alpine pussytoes
Antennaria corymbosa E. Nels.	Flattop pussytoes
Antennaria dimorpha (Nutt.) T. & G.	Low pussytoes
Antennaria rosea Greene	Rose pussytoes
Anthoxanthum odoratum L.	Sweet vernal grass
Apocynum androsaemifolium L.	Spreading dogbane
Apocynum pumilum Greene	Low dogbane
Arabis holboellii Hornem.	Holboell rockcress
Arbutus menziesii Pursh	Pacific madrone
Arctostaphylos canescens Eastw.	Hoary manzanita
Arctostaphylos columbiana Piper	Hairy manzanita
Arctostaphylos hispidula How.	Howell manzanita

Arctostaphylos nevadensis Gray	Pine-mat manzanita
Arctostaphylos patula Greene	Green manzanita
Arctostaphylos uva-ursi (L.) Spreng.	Kinnikinnick
Arctostaphylos viscida Parry	White-leaved manzanita
Arenaria capillaris var. *americana* Davis	Fescue sandwort
Arenaria formosa (Fisch.) Reg.	Slender mountain sandwort
Arenaria macrophylla Hook.	Bigleaf sandwort
Arenaria obtusiloba (Rydb.) Fern.	Blunt-leaved sandwort
Arenaria pumicola Cov.	Crater Lake sandwort
Aristida longiseta Steud.	Red threeawn
Arnica cordifolia Hook.	Heartleaf arnica
Arnica latifolia Bong.	Broadleaf arnica
Arnica sororia Greene	Sisters' arnica
Arrhenatherum elatius (L.) Mert.	Tall oatgrass
Artemisia arbuscula Nutt.	Low sagebrush
Artemisia cana Pursh	Silver sagebrush
Artemisia rigida (Nutt.) Gray	Stiff sagebrush
Artemisia spinescens Eat.	Bud sagebrush
Artemisia suksdorfii Piper	Suksdorf sagebrush
Artemisia tilesii Ledeb.	Mountain wormwood
Artemisia tridentata Nutt.	Big sagebrush
Artemisia tripartita Rydb.	Threetip sagebrush
Asarum caudatum Lindl.	Wild ginger
Aster alpigenus (T. & G.) Gray	Alpine aster
Aster canescens Pursh	Hoary aster
Aster conspicuus Lindl.	Snowy aster
Aster ledophyllus Gray	Cascades aster
Aster occidentalis (Nutt.) T. & G.	Western aster
Aster radulinus Gray	Rough-leaf aster
Aster scopulorum Gray	Crag aster
Aster subspicatus Nees	Douglas aster
Astragalus arrectus Gray	Hangingpod milkvetch
Astragalus filipes Torr. ex Gray	Threadstalk milkvetch
Astragalus lentiginosus Dougl. ex Hook.	Specklepod loco
Astragalus miser Dougl. ex Hook.	Starved milkvetch
Astragalus spaldingii Gray	Spaldings milkvetch
Astragalus stemophyllus T. & G.	Hangingpod milkvetch
Atriplex confertifolia (Torr. & Frem.) Wats.	Shadscale
Atriplex nuttallii Wats.	Nuttall's saltbush
Athyrium alpestre Butters	Alpine ladyfern
Athyrium filix-femina (L.) Roth	Ladyfern
Aulacomnium androgynum (Hedw.) Schwaegr.*	
Avena fatua L.	Wild oat
Balsamorhiza deltoidea Nutt.	Puget balsamroot
Balsamorhiza hookeri Nutt.	Hooker balsamroot
Balsamorhiza sagittata (Pursh) Nutt.	Arrowleaf balsamroot
Balsamorhiza serrata Nels. & Macbr.	Serrated balsamroot
Berberis aquilfolium Pursh	Tall Oregongrape
Berberis nervosa Pursh	Oregongrape
Berberis pumila Greene	Pygmy Oregongrape
Betula papyrifera Marsh.	Northwestern paper birch

Boschniakia strobilacea Gray	Ground-cone
Briza minor L.	Little quaking grass
Brodiaea coronaria (Salisb.) Jeps.	Harvest brodiaea
Brodiaea coronaria var. *macropoda* Torr.	Harvest brodiaea
Brodiaea multiflora Benth.	Many-flowered brodiaea
Bromus carinatus H. & A.	California brome
Bromus commutatus Schrad.	Hairy brome
Bromus laevipes Shear	Chinook brome
Bromus mollis L.	Soft brome
Bromus rigidus Roth	Ripgut brome
Bromus sitchensis Trin.	Alaska brome
Bromus tectorum L.	Cheatgrass brome
Bromus vulgaris (Hook.) Shear	Columbia brome
Calamagrostis nutkaensis (Presl) Steud.	Pacific reedgrass
Calamagrostis rubescens Buckl.	Pinegrass
Calochortus nitidus Dougl.	Big-pod mariposa lily
Caltha biflora DC.	Twinflower marshmarigold
Caltha leptosepala DC.	Elkslip marshmarigold
Campanula scouleri Hook.	Scouler bellflower
Cardamine bellidifolia L.	Alpine bittercress
Carex aperta Boott	Columbia sedge
Carex aquatilis Wahl.	Water sedge
Carex breweri Boott	Brewer sedge
Carex concinnoides Mack.	Northwestern sedge
Carex geyeri Boott	Elk sedge
Carex hoodii Boott	Hood sedge
Carex lyngbyei Hornem.	Lyngbye's sedge
Carex macrocephala Willd.	Bighead sedge
Carex nebraskensis Dew.	Nebraska sedge
Carex nigricans C. A. Mey.	Black alpine sedge
Carex obnupta Bail.	Slough sedge
Carex praegracilis W. Boott	Clustered field sedge
Carex rossii Boott	Ross sedge
Carex rostrata Stokes	Beaked sedge
Carex spectabilis Dew.	Showy sedge
Cassiope mertensiana (Bong.) G. Don	Western cassiope
Castanopsis chrysophylla (Dougl.) A. DC.	Golden chinkapin
Castanopsis chrysophylla var. *minor* Benth	Small golden chinkapin
Castilleja angustifolia (Nutt.) G. Don	Northwestern paintbrush
Castilleja arachnoidea Greenm.	Cotton paintbrush
Castilleja lutescens (Greenm.) Rydb.	Yellow paintbrush
Castilleja miniata Dougl. ex Hook.	Scarlet paintbrush
Castilleja parviflora Bong.	Smallflower paintbrush
Ceanothus cordulatus Kell.	Mountain whitethorn ceanothus
Ceanothus cuneatus (Hook.) Nutt.	Narrow-leaved buckbrush
Ceanothus integerrimus H. & A.	Deerbrush
Ceanothus prostratus Benth.	Squawcarpet
Ceanothus sanguineus Pursh	Redstem ceanothus
Ceanothus thyrsiflorus Esch.	Blueblossom
Ceanothus velutinus Dougl. ex Hook.	Snowbrush ceanothus
Ceanothus velutinus var. *laevigatus* T. & G.	Varnishleaf ceanothus

Ceanothus velutinus var. *velutinus* Dougl. ex Hook.	Snowbrush ceanothus
Celtis douglasii Planch.	Hackberry
Cercocarpus betuloides Nutt. in T. & G.	Birchleaf mountainmahogany
Cercocarpus ledifolius Nutt. in T. & G.	Curlleaf mountainmahogany
Chaenactis douglasii (Hook.) H. & A.	Falseyarrow
Chamaecyparis lawsoniana (A. Murr.) Parl.	Port-Orford-cedar
Chamaecyparis nootkatensis (D. Don) Spach	Alaska-cedar
Cheilanthes gracillima D. C. Eaton	Lace-fern
Cheilanthes siliquosa Maxon	Podfern
Chimaphila menziesii (R. Br.) Spreng.	Little prince's pine
Chimaphila umbellata (L.) Bart.	Western prince's pine
Chimaphila umbellata var. *occidentalis* Blake	Western prince's pine
Chrysothamnus nauseosus (Pall.) Brit.	Tall gray rabbitbrush
Chrysothamnus nauseosus var. *albicaulis* Hall. & Clem.	Whitestem gray rabbitbrush
Chrysothamnus viscidiflorus (Hook.) Nutt.	Tall green rabbitbrush
Cicuta douglasii (DC.) Coult. & Rose	Western waterhemlock
Circaea alpina L.	Alpine circaea
Cirsium vulgare (Savi) Airy-Shaw	Common thistle
Cladonia bellidiflora (Ach.) Schaer.*	
Cladonia coniocraea (Flk.) Spreng.*	
Cladonia grayii Merr.*	
Caldonia ecmocyna (Ach.) Nyl.*	
Cladonia ecmocyna var. *intermedia* (Robb.) Thoms.*	
Cladonia macrophyllodes Nyl.*	
Cladonia phyllophora Hoffm.*	
Cladonia rangiferina (L.) Wigg.*	
Claytonia megarhiza (Gray) Parry ex Wats.	Alpine springbeauty
Claytonia megarhiza var. *nivalis* (English) C. L. Hitchc.	Alpine springbeauty
Clintonia uniflora (Schult.) Kunth	Queencup beadlily
Collinsia parviflora Lindl.	Littleflower collinsia
Convolvulus soldanella L.	Coast morningglory
Coptis laciniata Gray	Cutleaf goldthread
Coptis occidentalis (Nutt.) T. & G.	Western goldthread
Corallorhiza maculata Raf.	Spotted coralroot
Cornus canadensis L.	Bunchberry dogwood
Cornus glabrata Benth.	Brown dogwood
Cornus nuttallii Aud. ex T. & G.	Pacific dogwood
Corylus cornuta Marsh. var. *californica* (DC.) Sharp	California hazel
Cotula coronopifolia L.	Bird brassbuttons
Crataegus columbiana Howell	Columbia hawthorn
Crataegus douglasii Lindl.	Black hawthorn
Cryptantha affinis (Gray) Greene	Slender cryptantha
Cryptogramma acrostichoides R. Br.	Parsley-fern
Cuscuta salina Engelm.	Salt-marsh dodder
Cynosurus echinatus L.	Hedgehog dogtail
Dactylis glomerata L.	Orchardgrass
Danthonia californica Boland.	California danthonia
Danthonia intermedia Vasey	Timber danthonia

Darlingtonia californica Torr.	California pitcher-plant
Daucus carota L.	Wild carrot
Deschampsia atropurpurea (Wahl.) Scheele	Mountain hairgrass
Deschampsia caespitosa (L.) Beauv.	Tufted hairgrass
Descurainia pinnata (Walt.) Britt.	Pinnate tansymustard
Dicranum fuscescens Turn.*	
Dicranum scoparium Hedw.*	
Dipsacus sylvestris Huds.	Common teasel
Disporum hookeri (Torr.) Britt.	Hooker's fairybells
Disporum smithii (Hook.) Piper	Smith's fairybells
Distichlis spicata (L.) Greene	Seashore saltgrass
Distichlis stricta (Torr.) Rydb.	Alkali saltgrass
Douglasia nivalis Lindl.	Snow douglasia
Draba aureola Wats.	Great alpine whitlow-grass
Drepanocladus aduncus (Hedw.) Warnst.*	
Dryas octopetala L.	White mountain avens
Dryopteris linnaeana C. Chr.	Oak fern
Dryopteris dilatata (Hoffm.) A. Gray	Mountain woodfern
Elymus caput-medusae L.	Medusahead wildrye
Elymus cinereus Scrib. & Mer.	Giant wildrye
Elymus flavescens Scribn. & Sm.	Yellow rye-grass
Elymus glaucus Buckl.	Blue wildrye
Elymus mollis Trin.	Dune wildrye
Elymus triticoides Buckl.	Creeping wildrye
Epilobium alpinum L. var. *clavatum* (Trel.) C. L. Hitchc.	Alpine willowweed
Epilobium angustifolium L.	Fireweed
Epilobium latifolium L.	Red willowweed
Epilobium paniculatum Nutt.	Autumn willowweed
Equisetum maximum Lam.	Giant horsetail
Erigeron aureus Greene	Golden fleabane
Erigeron filifolius Nutt.	Threadleaf fleabane
Erigeron linearis (Hook.) Piper	Lineleaf fleabane
Erigeron peregrinus (Pursh) Greene	Peregrine fleabane
Eriodictyon californicum (H. & A.) Greene	Yerba santa
Eriogonum compositum Dougl. ex Benth.	Northern buckwheat
Eriogonum douglasii Benth. in DC.	Douglas buckwheat
Eriogonum heracleoides Nutt.	Wyeth buckwheat
Eriogonum latifolium Smith	Broad-leaved eriogonum
Eriogonum marifolium T. & G.	Mountain buckwheat
Eriogonum microthecum Nutt.	Slenderbush buckwheat
Eriogonum niveum Dougl. ex Benth.	Snow eriogonum
Eriogonum piperi Greene	Piper buckwheat
Eriogonum pyrolaefolium Hook. ex A. Murr.	Oarleaf buckwheat
Eriogonum sphaerocephalum Dougl. ex Benth.	Rock buckwheat
Eriogonum thymoides Benth. in DC.	Thyme buckwheat
Eriogonum umbellatum Torr.	Sulfur buckwheat
Eriophorum angustifolium Roth.	Tall cottongrass
Eriophyllum lanatum (Pursh) Forbes	Common woolly sunflower
Erodium circutarium (L.) L'Her.	Filaree
Erythronium montanum Wats.	Avalanche fawnlily

Eurhynchium oreganum (Sull.) J. & S.*	
Eurotia lanata (Pursh) Moq.	Winterfat
Festuca californica Vasey	California fescue
Festuca dertonensis (All.) Asch. & Graeb.	Brome fescue
Festuca elatior L. var. *arundinacea* (Schrad.) Weinm.	Alta fescue
Festuca idahoensis Elm.	Idaho fescue
Festuca myuros L.	Rattail fescue
Festuca occidentalis Hook.	Western fescue
Festuca octoflora Walt.	Sixweeks fescue
Festuca ovina L.	Sheep fescue
Festuca rubra L.	Red fescue
Festuca scabrella Torr.	Rough fescue
Festuca subulata Trin.	Bearded fescue
Festuca viridula Vasey	Green fescue
Fontinalis antipyretica Hedw. var. *gigantea* (Sull.) Sull.*	
Fragaria chiloensis (L.) Duchesne	Coast strawberry
Fragaria vesca L. var. *bracteata* (Heller) Davis	Western wood strawberry
Fragaria virginiana Duchesne var. *platypetala* (Rydb.) Hall	Broad-petaled strawberry
Franseria chamissonis Less.	Silver beach-weed
Fraxinus latifolia Benth.	Oregon ash
Galium aparine L.	Cleavers bedstraw
Galium boreale L.	Northern bedstraw
Galium divaricatum Lam.	Spreading bedstraw
Galium triflorum Michx.	Sweetscented bedstraw
Garrya buxifolia Gray	Box-leaved garrya
Garrya elliptica Dougl.	Silk tassel bush
Garrya fremontii Torr.	Bear bush
Gastridium ventricosum (Gouan) Schinz. &Thell.	Nit grass
Gaultheria shallon Pursh	Salal
Gayophytum diffusum T. & G.	Spreading gayophytum
Gayophytum ramosissimum Nutt. ex T. & G.	Hairstem groundsmoke
Geranium viscosissimum F. & M.	Sticky geranium
Geum macrophyllum Willd.	Largeleaf avens
Gilia capitata Sims	Globe gilia
Gilia nuttallii Gray	Nuttall gilia
Glaux maritima L.	Sea milkwort
Glehnia leiocarpa Mathias	Beach silver-top
Goodyera oblongifolia Raf.	Rattlesnake plantain
Grayia spinosa (Hook.) Moq.	Spiny hopsage
Grindelia stricta DC.	Oregon gum-plant
Gymnomitrium varians (Lindb.) Schiffn.*	
Haplopappus liatriformis (Greene) St. John	Palouse haplopappus
Haplopappus stenophyllus Gray in Torr.	Narrow-leaved haplopappus
Helianthella uniflora (Nutt.) T. & G.	False sunflower
Heracleum lanatum Michx.	Common cowparsnip
Hieracium albertinum Farr	Western hawkweed
Hieracium albiflorum Hook.	White hawkweed
Hieracium cynoglossoides Arv.-Touv.	Houndstongue hawkweed

Hieracium gracile Hook.	Slender hawkweed
Holcus lanatus L.	Common velvetgrass
Holodiscus discolor (Pursh) Maxim.	Creambush oceanspray
Holodiscus glabrescens Heller	Gland oceanspray
Holosteum umbellatum L.	Jagged chickweed
Homalothecium megaptilum (Sull.) Robins.*	
Hulsea nana Gray in Torr.	Dwarf hulsea
Hydrophyllum fendleri (Gray) Heller var. *albifroms* (Heller) Macbr.	Fendler waterleaf
Hylocomium splendens (Hedw.) Bry. Eur.*	
Hypericum anagalloides C. & S.	Bog St. Johnswort
Hypericum perforatum L.	Common St. Johnswort
Hypnum circinale Hook.*	
Hypnum fertile Sendt.*	
Hypochaeris radicata L.	Spotted catsear
Iris chrysophylla How.	Slender-tubed iris
Iris douglasiana Herb. var. *oregonensis* Fost.	Douglas iris
Iris missouriensis Nutt.	Western iris
Iris tenax Dougl.	Oregon iris
Isothecium spiculiferum (Mitt.) Ren. & Card.*	
Jaumea carnosa (Less.) Gray	Jaumea
Juncus balticus Willd.	Baltic rush
Juncus drummondii E. Mey.	Drummond rush
Juncus effusus L.	Common rush
Juncus falcatus E. Mey.	Sickle-leaved rush
Juncus lesueurii Boland.	Salt rush
Juncus parryi Engelm.	Parry's rush
Juncus phaeocephalus Engelm.	Brown-headed rush
Juniperus communis L.	Common juniper
Juniperus occidentalis Hook.	Western juniper
Juniperus scopulorum Sarg.	Rocky Mountain juniper
Koeleria cristata (L.) Pers.	Prairie junegrass
Lactuca serriola L.	Prickly lettuce
Lagophylla ramosissima Nutt.	Slender rabbitleaf
Lappula redowskii (Hornem.) Greene	Western stickseed
Larix lyallii Parl.	Subalpine larch
Larix occidentalis Nutt.	Western larch
Lathyrus bijugatus White	Pinewoods peavine
Lathyrus littoralis (Nutt.) Endl.	Beach peavine
Lathyrus polyphyllus Nutt. ex T. & G.	Pacific peavine
Lathyrus sphaericus Retz.	Grass pea
Lecidea quadricolor (Dicks.) Borr. ex Hook.*	
Ledum glandulosum Nutt.	Mountain labradortea
Ledum glandulosum var. *columbianum* (Piper) C. L. Hitchc.	Mountain labradortea
Ledum groenlandicum Hulten	Bog labradortea
Leptarrhena pyrolifolia (D. Don) R. Br.	False saxifrage
Leptodactylon pungens (Torr.) Nutt.	Granite gilia
Libocedrus decurrens Torr.	Incense-cedar
Ligusticum apiifolium (Nutt.) Gray	Parsleyleaf licoriceroot
Ligusticum grayi Coult. & Rose	Gray's lovage

Lilaeopsis occidentalis Coult. & Rose	Western lilaeopsis
Linaria dalmatica (L.) Mill.	Dalmatian toadflax
Linnaea borealis L.	Twinflower
Listera caurina Piper	Western twayblade
Listera convallarioides (Sw.) Nutt.	Broad-lipped twayblade
Lithocarpus densiflorus (Hook. & Arn.) Rehd.	Tanoak
Lolium perenne L.	Perennial ryegrass
Lomatium angustatum St. John	Few-fruited lomatium
Lomatium cuspidatum Math. & Const.	Pointed-leaved lomatium
Lomatium dissectum (Nutt.) Math. & Const.	Lace-leaved leptotaenia
Lomatium macrocarpum (Nutt.) Coult. & Rose	Bigseed lomatium
Lomatium triternatum (Pursh) C. & T.	Nineleaf lomatium
Lonicera conjugialis Kell.	Purpleflower honeysuckle
Lonicera hispidula (Lindl.) Dougl. ex T. & G. var. *vacillans* (Benth.) Gray	California honeysuckle
Lonicera involucrata (Rich.) Banks	Bearberry honeysuckle
Luetkea pectinata (Pursh) Kuntze	Luetkea
Lupinus albifrons Benth.	White-leaved lupine
Lupinus caudatus Kell.	Tailcup lupine
Lupinus latifolius Agardh	Broadleaf lupine
Lupinus leucophyllus Dougl. ex Lindl.	Velvet lupine
Lupinus lepidus Dougl. ex Lindl.	Prairie lupine
Lupinus littoralis Dougl. ex Lindl.	Shore lupine
Lupinus saxosus Howell	Rock lupine
Lupinus sericeus Pursh	Silky lupine
Lysichitum americanum Hult. & St. John	Skunkcabbage
Madia madioides (Nutt.) Greene	Woodland tarweed
Maianthemum bifolium DC. var. *kamschaticum* (Gmel.) Jeps.	False lily-of-the-valley
Marah oreganus (T. & G.) Howell	Oregon wild cucumber
Melica bulbosa Geyer	Oniongrass
Melica geyeri Munro	Geyer oniongrass
Melica harfordii Boland.	Harford melic
Menziesia ferruginea Smith	Rustyleaf
Mesembryanthemum chilense Molina	Sea fig
Microseris troximoides Gray	False agoseris
Mimulus lewisii Pursh	Lewis monkeyflower
Mimulus nanus H. & A.	Dwarf monkeyflower
Mimulus tilingii Reg.	Clustered monkeyflower
Mitella stauropetala Piper	Sideflower miterwort
Mnium insigne Mitt.*	
Mnium menziesii (Hook.) C. Müll.*	
Monotropa hypopitys L.	Pinesap
Montia sibirica (L.) Howell	Western springbeauty
Muhlenbergia filiformis (Thurb.) Rydb.	Pullup muhly
Myosotis micrantha Pall. ex Lehm.	Smallflower forgetmenot
Myrica californica Cham.	Waxmyrtle
Oenanthe sarmentosa Presl ex DC.	Water parsley
Oplopanax horridum (J. E. Smith) Miq.	Devilsclub
Opuntia polyacantha Haw.	Plains pricklypear
Oryzopsis hymenoides (R. & S.) Ricker	Indian ricegrass

Osmaronia cerasiformis (T. & G.) Greene	Indian plum
Osmorhiza chilensis H. & A.	Mountain sweetroot
Oxalis oregana Nutt. ex T. & G.	Oregon oxalis
Oxyria digyna (L.) Hill	Alpine mountainsorrel
Pachistima myrsinites (Pursh) Raf.	Oregon boxwood
Parnassia fimbriata Konig	Rockymountain parnassia
Peltigera aphthosa (L.) Willd.*	
Penstemon aridus Rydb.	Stiffleaf penstemon
Penstemon cardwellii Howell	Cardwell's penstemon
Penstemon cusickii Gray	Cusick penstemon
Penstemon davidsonii Greene	Davidson penstemon
Penstemon procerus Dougl.	Tinybloom penstemon
Penstemon rydbergii A. Nels.	Rydberg penstemon
Penstemon speciosus Dougl. ex Lindl.	Royal penstemon
Petasites frigidus (L.) Fries var. *nivalis* (Greene) Cronq.	Alpine coltsfoot
Phacelia hastata Dougl. ex Lehm.	Whiteleaf phacelia
Phacelia heterophylla Pursh	Varileaf phacelia
Philadelphus lewisii Pursh	Mockorange
Philonotis fontana (Hedw.) Brid.*	
Phleum alpinum L.	Alpine timothy
Phlox diffusa Benth.	Spreading phlox
Phlox douglasii Hook.	Tufted phlox
Phlox gracilis (Hook.) Greene	Pink annual phlox
Phlox hoodii Rich.	Hoods phlox
Phlox longifolia Nutt.	Longleaf phlox
Phyllodoce empetriformis (S.W.) D. Don	Red mountainheath
Physocarpus malvaceus (Greene) Kuntze	Mallow ninebark
Picea engelmannii (Parry) Engelm.	Engelmann spruce
Picea sitchensis (Bong.) Carr.	Sitka spruce
Pinus albicaulis Engelm.	Whitebark pine
Pinus attenuata Lemm.	Knobcone pine
Pinus cembra L.	Swiss stone pine
Pinus contorta Dougl.	Lodgepole pine
Pinus jeffreyi Grev. & Balf.	Jeffrey pine
Pinus lambertiana Dougl.	Sugar pine
Pinus monticola Dougl.	Western white pine
Pinus ponderosa Laws.	Ponderosa pine
Pinus pumila Regel	Japanese stone pine
Plantago lanceolata L.	English plantain
Plantago maritima L.	Seaside plantain
Plantago patagonica Jacq.	Indianwheat
Plantago subnuda Pilgr.	Tall coast plantain
Plectritis macrocera T. & G.	Longhorn plectritis
Poa ampla Merr.	Alpine bluegrass
Poa compressa L.	Canada bluegrass
Poa curtifolia Scribn.	Mt. Stuart bluegrass
Poa cusickii Vasey	Cusick bluegrass
Poa macrantha Vasey	Seashore bluegrass
Poa nervosa (Hook.) Vasey	Wheeler bluegrass
Poa pratensis L.	Kentucky bluegrass
Poa pringlei Scribn.	Pringle bluegrass

Poa scabrella Torr.	Pine bluegrass
Poa secunda Presl	Sandberg bluegrass
Pogonatum alpinum (Hedw.) Roehl*	
Pohlia nutans (Hedw.) Lindb.*	
Polemonium californicum Eastw.	California polemonium
Polemonium elegans Greene	Slender polemonium
Polemonium pulcherrimum Hook.	Skunkleaf polemonium
Polygonum bistortoides Pursh	American bistort
Polygonum newberryi Small	Newberry fleeceflower
Polygonum paronychia Cham. & Schlect.	Nailwort knotweed
Polygonum phytolaccaefolium Meisn. ex Small	Pokeweed fleeceflower
Polystichum munitum (Kaulf.) Presl	Swordfern
Polytrichadelphus lyallii Mitt.*	
Polytrichum juniperinum Hedw.*	
Polytrichum norvegicum Hedw.*	
Polytrichum piliferum Hedw.*	
Populus tremuloides Michx.	Quaking aspen
Populus trichocarpa Torr. & Gray	Black cottonwood
Porella navicularis (L. & L.) Lindb.*	
Potentilla anserina L.	Silver weed
Potentilla flabellifolia Hook. ex T. & G.	Fanleaf cinquefoil
Potentilla fruticosa L.	Shrubby cinquefoil
Potentilla glandulosa Lindl.	Gland cinquefoil
Potentilla gracilis Dougl. ex Hook.	Beauty cinquefoil
Prunella vulgaris L. var. *lanceolata* (Bart.) Fern.	Heal-all
Prunus avium L.	Mazzard cherry
Prunus emarginata Dougl.	Bitter cherry
Prunus virginiana L.	Common chokecherry
Prunus virginiana var. *melanocarpa* (A. Nels.) Sarg.	Chokecherry
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Psoralea lanceolata Pursh	Lanceleaf scurfpea
Pteridium aquilinum (L.) Kuhn. var. *pubescens* Underw.	Bracken fern
Pterospora andromedea Nutt.	Pine drops
Ptilidium californicum (Aust.) U. & C.*	
Puccinellia pumila (Vas.) Hitchc.	Alaska alkali grass
Purshia tridentata (Pursh) DC.	Bitterbrush
Pyrola asarifolia Michx.	Large pyrola
Pyrola picta Smith in Rees	Whitevein pyrola
Pyrola secunda L.	One-sided wintergreen
Quercus chrysolepis Liebm.	Canyon live oak
Quercus garryana Dougl.	Oregon white oak
Quercus kelloggii Newb.	California black oak
Quercus sadleriana R. Br.	Sadler oak
Quercus vaccinifolia Kellogg	Huckleberry oak
Raillardella argentea Gray	Raillardella
Ranunculus flammula L.	Smaller creeping buttercup
Ranunculus occidentalis Nutt.	Western buttercup
Rhacomitrium canescens (Hedw.) Brid. var. *ericoides* (Brid.) B.S.G.*	

Rhacomitrium heterostichum (Hedw.) Brid.*	
Rhacomitrium lanuginosum (Hedw.) Brid.*	
Rhacomitrium patens (Hedw.) Hueb.*	
Rhacomitrium sudeticum (Funck) B.S.G.*	
Rhamnus californica Esch. var. *occidentalis* (How.) Jeps.	California coffee berry
Rhamnus purshiana DC.	Cascara
Rhododendron albiflorum Hook.	Cascades azalea
Rhododendron macrophyllum G. Don	Pacific rhododendron
Rhododendron occidentale (T. & G.) Gray	Western azalea
Rhus diversiloba T. & G.	Pacific poison oak
Rhus glabra L.	Smooth sumac
Rhus trilobata Nutt. in T. & G.	Skunkbrush sumac
Rhytidiadelphus loreus (Hedw.) Warnst.*	
Rhytidiadelphus triquetrus (Hedw.) Warnst.*	
Rhytidiopsis robusta (Hook.) Broth.*	
Ribes cereum Dougl.	Wax currant
Ribes lacustre (Pers.) Poir.	Prickly currant
Ribes marshalli Greene	Hupa gooseberry
Ribes menziesii Pursh	Menzies gooseberry
Ribes velutinum Greene	Desert gooseberry
Ribes viscosissimum Pursh	Sticky currant
Rosa eglanteria L.	Sweetbriar rose
Rosa gymnocarpa Nutt.	Baldhip rose
Rosa nutkana Presl	Nootka rose
Rosa woodsii Lindl.	Woods rose
Rubus lasiococcus Gray	Dwarf blackberry
Rubus nivalis Dougl. ex Hook.	Snow dewberry
Rubus parviflorus Nutt.	Thimbleberry
Rubus pedatus J. E. Smith	Strawberry-leaf blackberry
Rubus spectabilis Pursh	Salmonberry
Rubus ursinus Cham. & Schlecht.	Trailing blackberry
Rumex acetosella L.	Sheep sorrel
Rumex venosus Pursh	Veiny dock
Salicornia ambigua Michx.	Woody glasswort
Salix hookeriana Barr.	Coast willow
Salix nivalis Hook.	Snow willow
Salix scouleriana Barr.	Scouler's willow
Salix sitchensis Sanson in Bong.	Sitka willow
Salsola kali L.	Russian thistle
Sambucus cerulea Raf.	Blue elderberry
Sambucus racemosa L. var. *melanocarpa* (Gray) McMinn	Black elderberry
Sanicula bipinnatifida Dougl. ex Hook.	Purple sanicle
Sanicula crassicaulis Poepp.	Western snake-root
Sarcobatus vermiculatus (Hook.) Torr.	Black greasewood
Sarcodes sanguinea Torr.	Snow plant
Satureja douglasii (Benth.) Briq.	Yerba buena
Saussurea americana Eat.	Saussurea
Saxifraga tolmiei T. & G.	Tolmie saxifrage
Scapania bolanderi Aust.*	
Scirpus americanus Pers.	Three-square

Scirpus pacificus Britt.	Pacific coast bulrush
Scirpus setaceus L.	Bristle-leaved sedge
Scirpus validus Vahl	American great bulrush
Scrophularia lanceolata Pursh	Lanceleaf figwort
Sedum oregonense (Wats.) Peck	Creamy stonecrop
Selaginella wallacei Hieron.	Wallace's selaginella
Senecio fremontii T. & G.	Low mountain senecio
Senecio integerrimus Nutt.	Western groundsel
Senecio pauperculus Michx.	Balsam groundsel
Senecio sylvaticus L.	Woodland groundsel
Sequoia sempervirens (D. Don) Endl.	Coast redwood
Sherardia arvensis L.	Bluefield madder
Sidalcea malvaeflora (DC.) Gray	Mallow sidalcea
Sidalcea oregana (Nutt.) Gray	Oregon checkermallow
Silene acaulis L.	Moss silene
Silene parryi (Wats.) Hitchc. & Maguire	Parrys silene
Sisymbrium altissimum L.	Tumbleweed
Sisyrinchium californicum (Ker) Dryand.	Golden blue-eyed grass
Sitanion hystrix J. G. Sm.	Bottlebrush squirreltail
Sitanion jubatum J. G. Sm.	Big squirreltail
Smelowskia calycina (Steph.) C. A. Mey.	Alpine smelowskia
Smelowskia ovalis M. E. Jones	Short-fruit smelowskia
Smilacina sessilifolia (J. G. Bak.) Nutt.	Slim solomonplume
Smilacina stellata (L.) Desf.	Starry solomonplume
Solidago canadensis L.	Canada goldenrod
Solidago missouriensis Nutt.	Missouri goldenrod
Spiraea betulifolia Pall. var. *lucida* (Dougl.) C. L. Hitchc.	Shinyleaf spirea
Spiraea douglasii Hook.	Douglas spirea
Spiraea douglasii var. *menziesii* (Hook.) Presl	Menzies spirea
Sporobolus cryptandrus (Torr.) Gray	Sand dropseed
Spraguea umbellata Torr. in Smith	Pussypaws
Stachys cooleyae Heller	Cooleys hedge nettle
Stachys mexicana Benth.	Great hedge nettle
Stellaria crispa Cham. & Schlecht.	Crisped starwort
Stereocaulon paschale (L.) Hoffm.*	
Stipa californica Merr. & Davy	California needlegrass
Stipa columbiana Macoun	Columbia needlegrass
Stipa comata Trin. & Rupr.	Needle and thread
Stipa lemmonii (Vas.) Scribn.	Lemmon needlegrass
Stipa lettermanii Vasey	Letterman needlegrass
Stipa occidentalis Thurb.	Western needlegrass
Stipa thurberiana Piper	Thurber needlegrass
Streptopus curvipes Vaill.	Purple twistedstalk
Struthiopteris spicant (L.) Weis.	Deerfern
Symphoricarpos albus (L.) Blake	Common snowberry
Symphoricarpos mollis Nutt. var. *hesperius* (G. N. Jones) Cronq.	Creeping snowberry
Symphoricarpos rotundifolius Gray	Round-leaved snowberry
Synthyris reniformis (Dougl.) Benth.	Snowqueen
Taraxacum officinale Weber	Common dandelion

Taxus brevifolia Nutt.	Western yew
Tellima grandiflora (Pursh) Dougl.	Alaska fringecup
Tetradymia canescens DC.	Gray horsebush
Thalictrum occidentale Gray	Western meadow-rue
Thlaspi alpestre L.	Blue pennycress
Thlaspi arvense L.	Penny-cress
Thuja plicata Donn	Western redcedar
Tiarella trifoliata L.	Three-leaved coolwort
Tiarella unifoliata Hook.	Western coolwort
Tolmiea menziesii (Pursh) T. & G.	Youth-on-age
Torilis arvensis (Huds.) Link	Field hedge-parsley
Torilis nodosa (L.) Gaertn.	Knotted hedge-parsley
Tortula brevipes (Lesq.) Broth.*	
Tortula ruralis (Hedw.) Gaertn., Meyer & Schreb.*	
Tortula princeps De Not.*	
Trautvetteria caroliniensis (Walt.) Vail	False bugbane
Trientalis latifolia Hook.	Starflower
Trifolium gymnocarpon Nutt.	Tufted clover
Trifolium longipes Nutt.	Long-stalked clover
Trifolium macrocephalum (Pursh) Poir.	Big-headed clover
Trifolium willdenovii Lehm.	Spring-bank clover
Triglochin maritima L.	Seaside arrow-grass
Trillium ovatum Pursh	White trillium
Trisetum canescens Buckl.	Tall trisetum
Trisetum cernuum Trin.	Nodding trisetum
Tsuga heterophylla (Raf.) Sarg.	Western hemlock
Tsuga mertensiana (Bong.) Carr.	Mountain hemlock
Ulex europaeus L.	Common gorse
Umbellularia californica (Hook. & Arn.) Nutt.	California laurel
Urtica dioica L.	Bigsting nettle
Vaccinium alaskaense Howell	Alaska huckleberry
Vaccinium caespitosum Michx.	Dwarf huckleberry
Vaccinium deliciosum Piper	Blueleaf huckleberry
Vaccinium membranaceum Dougl. ex Hook.	Big huckleberry
Vaccinium occidentale Gray	Westernbog huckleberry
Vaccinium ovalifolium Smith	Ovalleaf huckleberry
Vaccinium ovatum Pursh	Evergreen huckleberry
Vaccinium parvifolium Smith	Red huckleberry
Vaccinium scoparium Leiberg	Grouse huckleberry
Valeriana sitchensis Bong.	Sitka valerian
Vancouveria hexandra (Hook.) Morr. & Dec.	White inside-out-flower
Veratrum viride Ait.	American false hellebore
Veronica peregrina L.	Purslane speedwell
Vicia americana Muhl. ex Willd.	American vetch
Vicia americana var. *truncata* Brew.	American vetch
Vicia tetrasperma (L.) Moench	Slender vetch
Viola glabella Nutt.	Wood violet
Viola sempervirens Greene	Evergreen violet
Whipplea modesta Torr.	Whipple vine
Xerophyllum tenax (Pursh) Nutt.	Common beargrass
Zigadenus fremontii Torr.	Fremont deathcamas
Zigadenus paniculatus (Nutt.) Wats.	Foothill deathcamas

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THE EFFECT OF ASPHALT AND WAX EMULSIONS ON MOISTURE CHANGES IN SLASH

JAMES L. MURPHY
CHARLES W. PHILPOT
MORRIS J. GARBER

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JAMES L. MURPHY, Research Forester, Forest Fire Science Project, Pacific Northwest Forest and Range Experiment Station, is stationed at Seattle, Washington.

CHARLES W. PHILPOT is Research Forester at Northern Forest Fire Laboratory, Intermountain Forest and Range Experiment Station, Missoula, Montana.

MORRIS J. GARBER, a Biometrician, is Director, Computer Center, and Head, Biometrical Laboratory, University of California at Riverside.

INTRODUCTION

Disposal of logging slash is one of the forest manager's biggest problems. slash is not disposed of, a serious fire hazard may result, and regeneration y be prevented because of an inadequate seedbed or resistance to planting. resters can dispose of slash by burning or by generally more expensive chanical methods such as chipping. Over much of the West, however, burn- ; is risky during the hot, dry summer months, and slash may be too wet to rn during the fall or winter. A water-repellent coating sprayed on might p keep the slash dry until conditions are safe for burning.

Asphalt and wax emulsions have been suggested as protective coatings. ter-base asphalt emulsions known as slow-set and rapid-set (SS-1 and RS-1) ve been developed. Grade SS-1 is known as Laykold Slash Cover, an asphaltum nt. A primer-based asphalt solution requiring an organic solvent has also en tried. Lumber wax and a commercial soil sealant wax have also been ggested as slash coatings.

Kirkmire[1/] tested the effectiveness of asphalt and wax emulsions. He ind that asphalt emulsion grade SS-1 was more effective than a wax emulsion keeping slash dry enough to burn after 1-1/2 inches of precipitation. McNie[2/] ported that coating slash piles along a right-of-way with asphalt and wax ulsions helped dispose of slash more safely than did diesel oil used as a fuel oster. He found that the cost of slash disposal with asphalt emulsions was out the same or less than the traditional method of firing slash piles with sel oil. The Klamath National Forest[3/] found that the cost of treating slash steep ground with SS-1 grade emulsion was expensive, and they encountered merous difficulties in handling, mixing, and application.

1/ Kirkmire, Nicholas J. Report on preliminary tests on water-proofing rays for logging slash. 9 pp. 1961. (Unpublished report on file at Washington rest Protection Association.)

2/ McNie, John C. How to dispose of slash better at less cost. Forest l. 91(9): 69. 1964.

3/ U.S.D.A. Forest Service, R-5. Report on the asphalt emulsion SS-1 eatment of right-of-way piled construction slash. 4 pp. 1963. (Unpublished port on file at Klamath National Forest.)

A feasibility study by Schimke[4/] found that slash piles sprayed with asphalt and wax emulsions could be burned during the winter when uncoated piles could not be burned. Schimke and Murphy[5/] showed that coated dry slash piles burned better than uncoated piles after fall rains. However, they stated that treated slash piles should be burned before 8 to 10 inches of rain have fallen. They found that SS-1 grade was best in terms of availability, cost, and performance. A 1:1 dilution ratio (asphalt to water) was more effective than either 1:3 or 1:5.

Murphy and Philpot[6/] analyzed the added fuel value of slash coatings. They found that a petroleum-based protective coating, applied at a rate of 25 gallons per 100 cubic feet of piled slash, contributed 1.2 to 3.4 percent of heat value to the pile. Apparently the major effect of the coatings is in relation to moisture control.

Dry logging slash, sprayed with asphalt and wax emulsions, has been successfully kept dry for later burning. Schimke and Dougherty[7/] tried the same treatments on green slash, since it would be cheaper and easier to treat slash at the time of its creation. Field trials using SS-1 and lumber wax on green slash showed that these protective coatings prevented satisfactory drying and over half of the treated piles did not burn well. The asphalt-emulsion-treated piles burned somewhat better than the lumber-wax-treated piles, although 18.5 inches of rain fell after the piles were treated.

METHODS

Our study was designed to answer the following questions:

1. What are the patterns of moisture loss or gain for slash treated with various protective coatings?

2. What is the effect of shading on these moisture patterns?

[4/] Schimke, H. E. Asphalt emulsions aid in burning slash. U.S.D.A. Forest Serv. Pacific Southwest Forest & Range Exp. Sta. 3 pp. 1963.

Schimke, H. E. Chipping of thinning slash on fuel-breaks. Pacific Southwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Res. Note PSW-58, 4 pp. 1965.

[5/] Schimke, H. E., and Murphy, J. L. Protective coatings of asphalt and wax emulsions for better slash burning. Fire Contr. Notes, Vol. 27, No. 2, 3 pp. 1966.

[6/] Murphy, James L., and Philpot, Charles W. Do petroleum-based protective coatings add fuel value to slash? Pacific Southwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Res. Note PSW-81, 3 pp. 1965.

[7/] Schimke, Harry E., and Dougherty, Ronald H. Coating green slash... asphalt and wax prevent drying. Pacific Southwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Res. Note PSW-143, 2 pp. 1967.

3. What are the differences in water repellency between a primer, two asphalt emulsions, and two wax emulsions?

4. What mixing ratio is the most effective?

A laboratory study using a standard fuel and treatment method was devised. Green and dry ponderosa pine (*Pinus ponderosa* Laws.) slash was obtained from pole-sized trees at about 4,000-foot elevation near Sonora, California. The dry slash was cut and broadcast 1 year prior to the study. Green material was cut 1 week before the study began.

Ninety green and 90 dry sections about 3 inches in diameter and 16 inches long were cut. A 1-inch-thick disk was removed from the center of these samples for initial moisture determination. The two resulting pieces, 7-1/2 inches long, were numbered and identified with aluminum tags (fig. 1). The matched samples were then weighed; one was used as a control, and the other was dipped immediately in the coating material. Each treatment included three controls and three test samples (table 1). Of the five asphalt- and wax-in-water coatings, four were tested at three different mixing ratios by volume: 1:1, 1:3, and 1:5. The primer was diluted with xylene, $C_6H_4(CH_3)_2$. The 1:5 dilution of RS-1 was impossible to keep from separating and was not tested.

Figure 1.--Slash samples prior to dipping.

Table 1.--Summary of asphalt and wax emulsion treatments of slash by mixing ratio according to test conditions

Type of emulsion[1/]	Sun		Shade	
	Green	Dry	Green	Dry
SS-1	1:1	1:1	1:1	1:1
SS-1	1:3	1:3	1:3	1:3
SS-1	1:5	1:5	1:5	1:5
RS-1	1:1	1:1	1:1	1:1
RS-1	1:3	1:3	1:3	1:3
Primer	1:1	1:1	1:1	1:1
Primer	1:3	1:3	1:3	1:3
Primer	1:5	1:5	1:5	1:5
Lumber wax	1:1	1:1	1:1	1:1
Lumber wax	1:3	1:3	1:3	1:3
Lumber wax	1:5	1:5	1:5	1:5
Soil sealant wax	1:1	1:1	1:1	1:1
Soil sealant wax	1:3	1:3	1:3	1:3
Soil sealant wax	1:5	1:5	1:5	1:5

[1/] Each treatment has three replications and three controls except RS-1.

Each sample was completely submerged in the appropriate coating for 1 minute. The sample was agitated during this time to eliminate entrained air and insure complete coverage. No attempt was made to duplicate field application. The coatings were allowed to harden and dry and the samples and the controls were then hung in one of two test exposures: the sun or shade (figs. 2 and 3). The shade environment was protected by two rows of trees, 10-15 feet high, along either side of the supporting poles.

Both sun and shade poles were oriented north-south. The samples were weighed at 2-week intervals and after major rainstorms. Any loss or gain of weight was assumed to be due to changes in the water content of the sample. At the end of the study, the moisture content determined by weight change was checked by an ovendried disk from the center of each sample. There were only slight differences, and these were due to loss of bark and coating material.

Two major rainstorms of over 1 inch, lasting several days, seven minor storms, and one artificial storm of 3 inches during a 1-1/2-hour period the last week of the 5-1/2-month study occurred. After the artificial storm, the samples were checked for moisture gain and allowed to dry for 1 week after which they were reweighed and the study was terminated. Standard least squares, regression, and variance analysis procedures were used for data reduction and statistical evaluation.

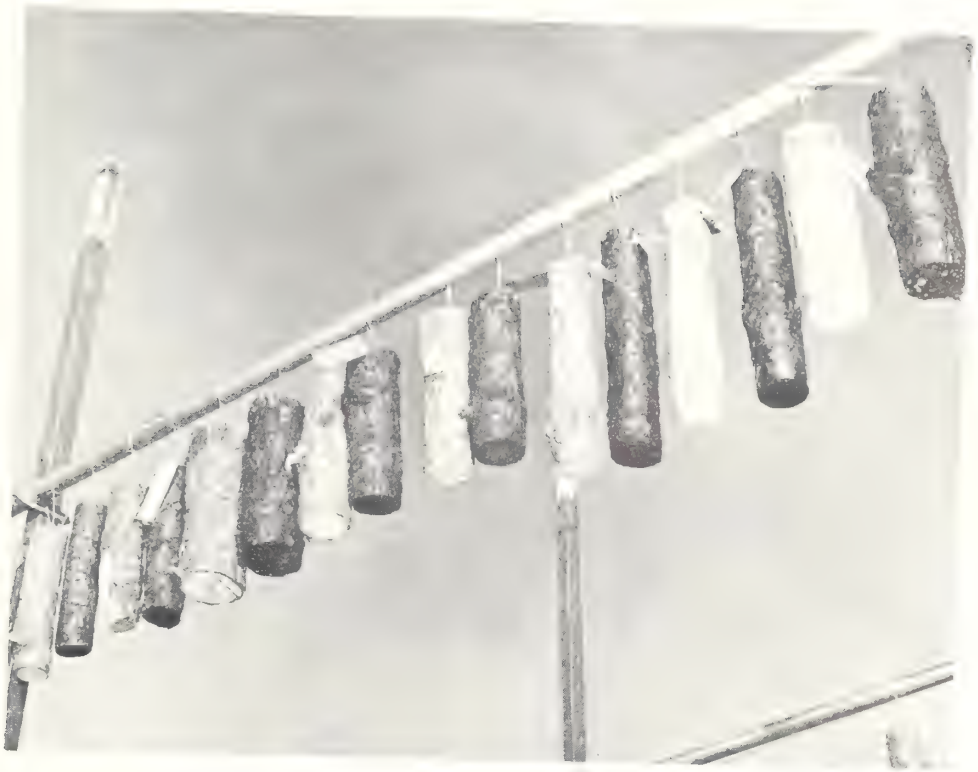

Figure 2.--Treated and control samples hanging.

Figure 3.--Samples hanging in the shaded environment.

RESULTS

GREEN SAMPLES

The application of the two asphalt emulsions, the primer, and the two wax emulsions had an effect upon drying of the green slash. Figures 4, 5, and 6 show examples of this. The treated samples lost moisture more slowly and had less tendency to pick up water during precipitation periods than did the green controls. The primer coating had the least effect on moisture changes in comparison with its controls (fig. 5). The other four coatings all had a pronounced retarding effect upon drying, the 1:1 mixing ratio having the greatest.

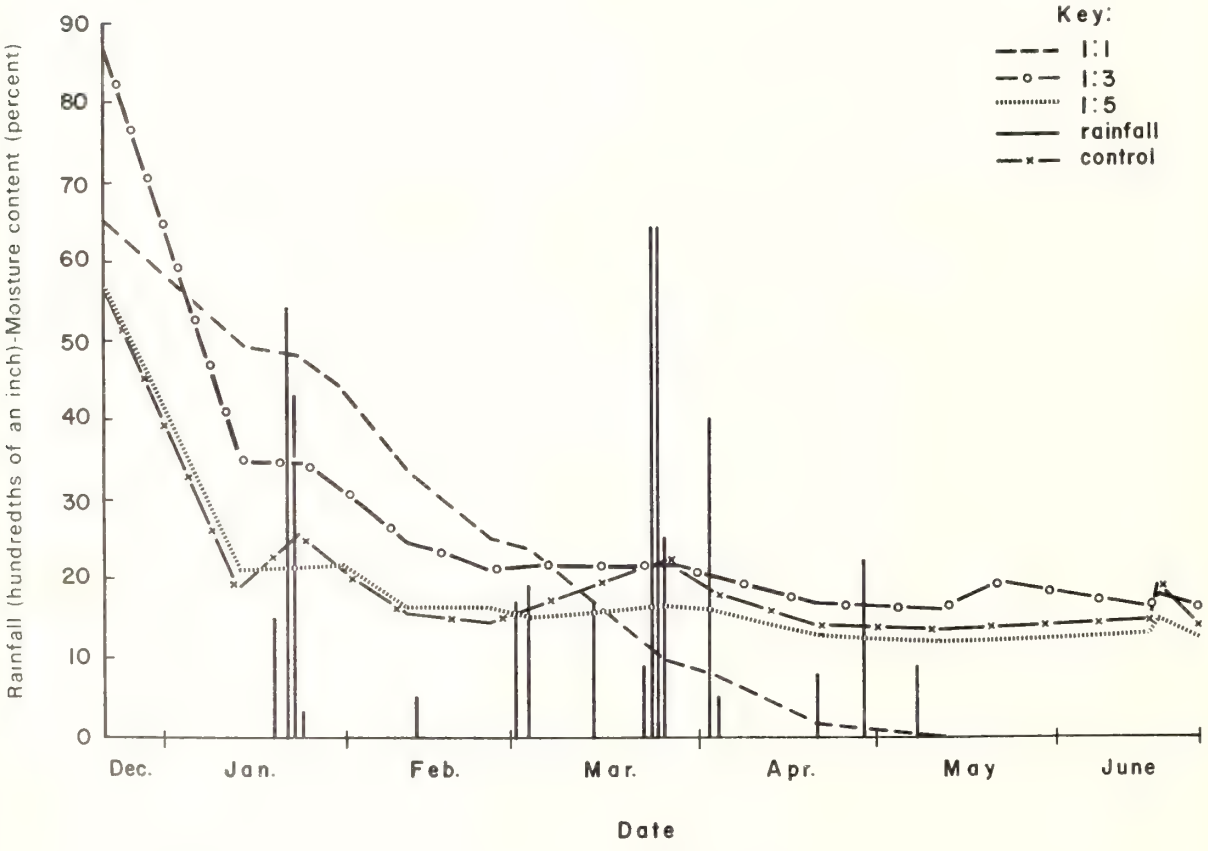

Figure 4.--Drying curves for three mixing ratios of SS-1 and controls in the sun environment.

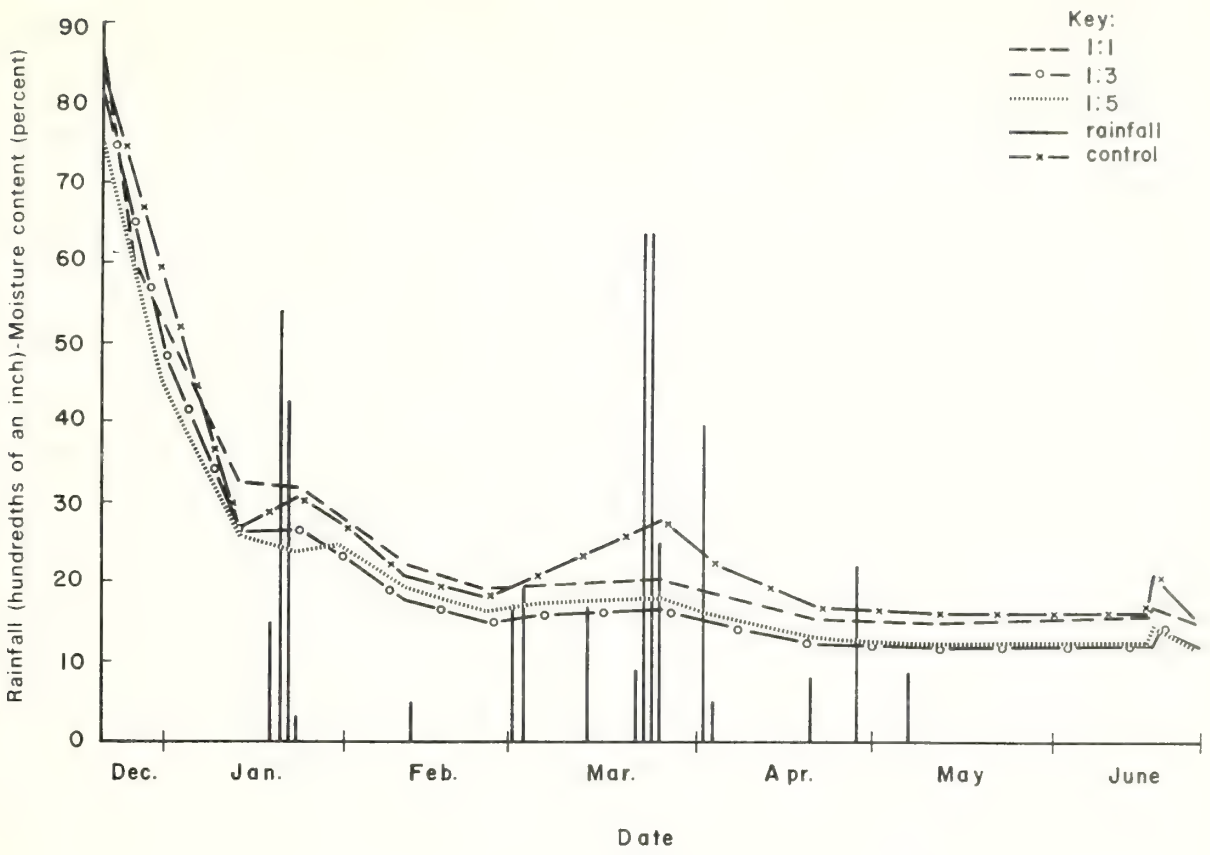

Figure 5.--Drying curves for three mixing ratios of primer and controls in the sun environment.

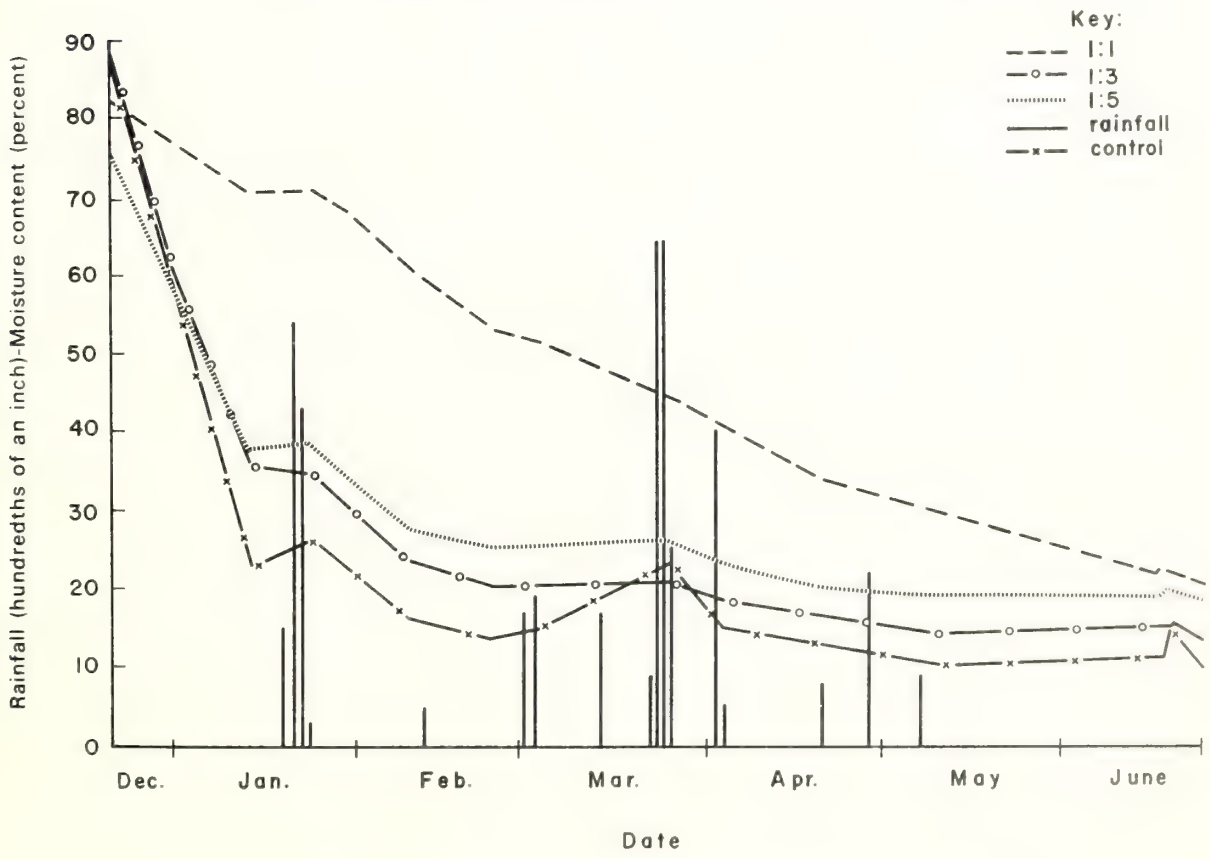

Figure 6.--Drying curves for three mixing ratios of sealant wax in the sun environment.

Prediction curves were calculated from sample weighings on rainless days to show the effect of the coatings on drying rate without rain. Curves of these relationships in the sun by mixing ratio for SS-1, primer, and sealant wax are shown in figures 7, 8, and 9. Table 2 gives the significance of the differences between predicted moisture without rain and actual moisture with rain as determined by the *F* test.

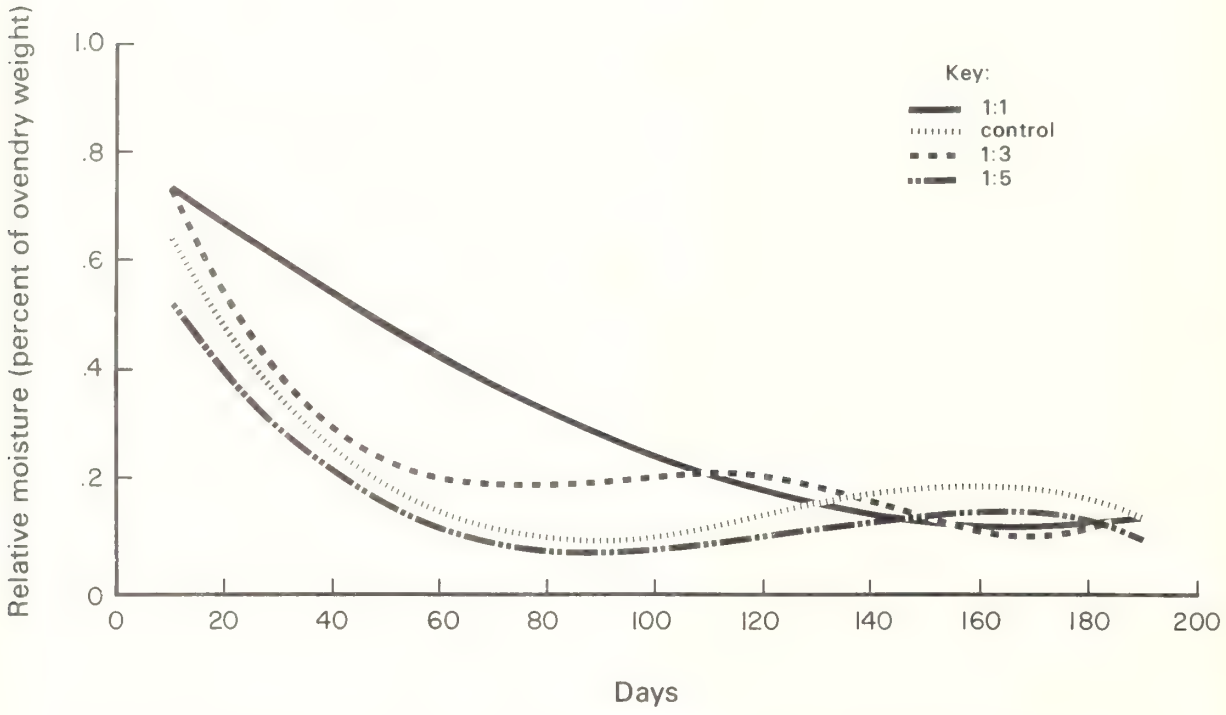

Figure 7.--Predicted drying curves of green slash treated with SS-1, in the sun environment and without rain.

The curve shapes in figures 7 to 9 are important. It will be noted that, generally, the curves depicting moisture content of treated samples versus time fall downward and to the right at a more constant rate than the curves showing moisture trends of untreated samples. This general result varies widely by mixing ratios, however. The curves of moisture trends of samples treated with SS-1 at 1:1 ratio, under sun conditions, most nearly approached a normal drying curve. This coating and ratio had the greatest effect on moisture loss or gain by green slash. The primer curves most nearly resembled those of their controls. Primer had the least effect on moisture loss or gain.

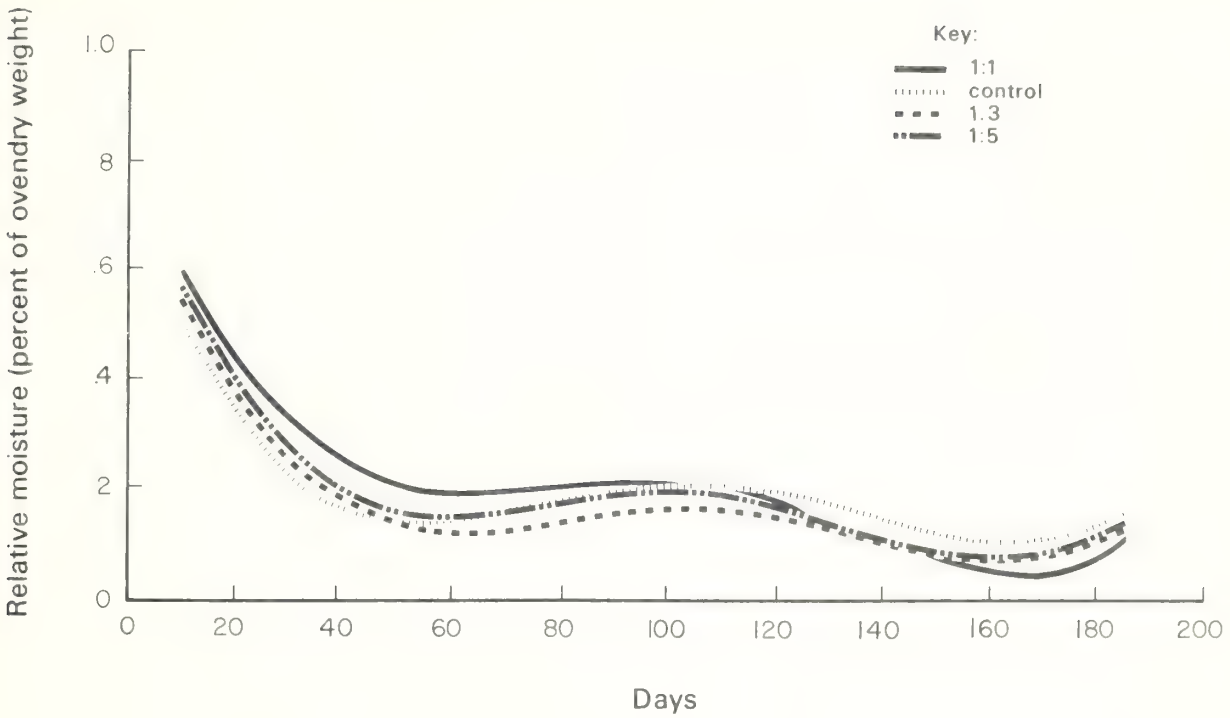

Figure 8.--Predicted drying curves of green slash treated with primer, in the sun environment and without rain.

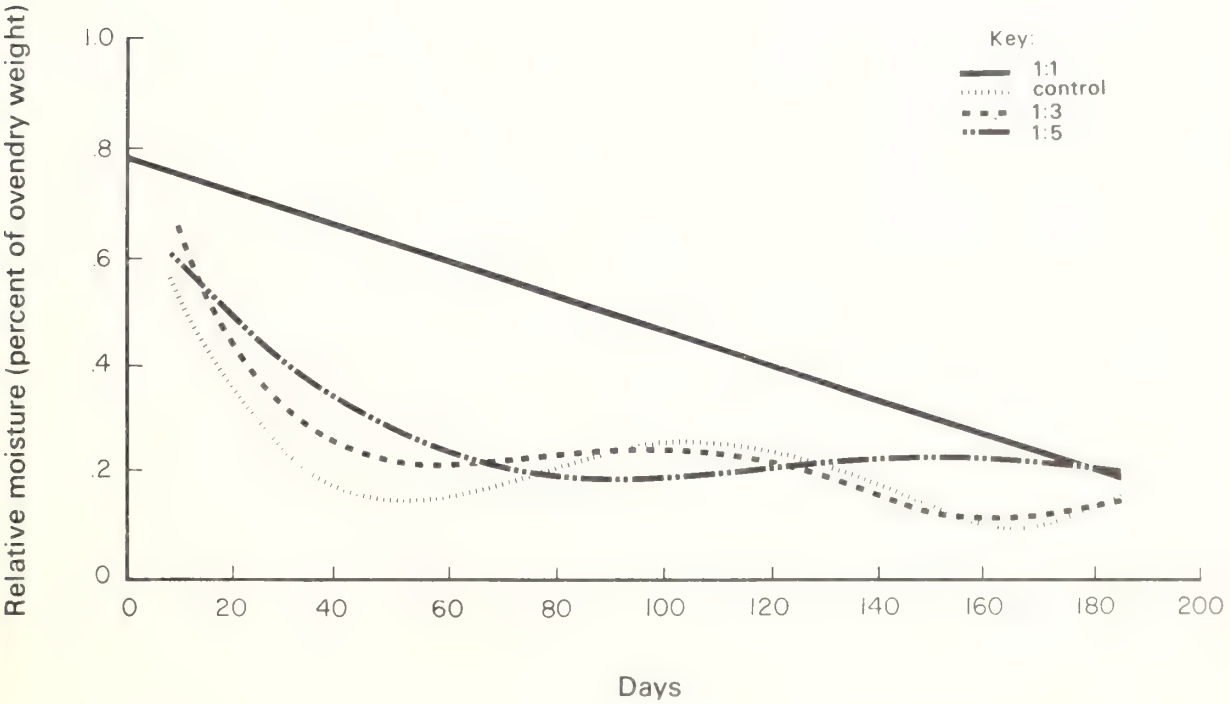

Figure 9.--Predicted drying curves of green slash treated with sealant wax, in the sun environment and without rain.

Table 2.--Comparison of differences between "rain date" and predicted values[1/]

$$F_{1,\ n-4} = \frac{K(y - \hat{y})^2}{MS_E}$$

Mixing ratio and rain date	SS-1		RS-1		Primer		Sealant wax		Lumber wax	
	Sun	Shade	Sun	Shade	Sun	Shade	Sun	Shade	Sun	Shade
Control										
Jan. 23	2.53	70.83*	52.66**	48.05**	67.13**	97.17**	130.13**	92.60**	113.29**	82.12**
Mar. 25	10.18*	1.95	10.97*	2.29	14.80*	14.79*	.44	15.74*	.76	10.88*
June 17	8.33*	1.34	10.78*	.10	11.06*	2.94	6.06	.01	.96	17.48*
1:1										
Jan. 23	80.07**	8.57*	455.83**	7.92**	19.40**	0	7.66*	.08	.17	49.53**
Mar. 25	2.23	1.92	153.46**	1.94	.06	3.26	.24	12.08*	1.87	43.47**
June 17	.03	34.87**	7.73*	.02	.09	.65	9.51*	2.13	3.83	3.68
1:3										
Jan. 23	22.37**	12.89**	194.50**	47.71**	17.32*	14.85*	45.08**	24.49*	.13	0
Mar. 25	.02	27.83**	143.73**	43.80**	.63	2.68	3.32	13.14*	4.68	4.13
June 17	.38	8.70*	12.03*	11.67*	.13	.22	1.69	13.63*	.65	1.08
1:5										
Jan. 23	.69	42.18*	(2/)	(2/)	15.83*	26.03*	2.63	62.51**	.03	22.75*
Mar. 25	6.40*	4.20	(2/)	(2/)	.40	21.20*	10.93*	8.65*	5.16	23.47*
June 17	1.45	1.50	(2/)	(2/)	.11	.95	1.10	.19	.69	15.70*

1/ From figures 7, 8, and 9.
2/ Not tested.
* Significant at the 10-percent level.
** Significant at the 2-1/2-percent level.

The 1:1 ratio provided the best water repellent coating in most cases. As the amount of dilution increased, the protective qualities decreased. Shade had an effect upon drying, as expected. The controls lost moisture more slowly in the shade than in the sun. So did the treated samples, with the waxes showing the least difference in drying patterns between sun and shade.

The total time for green slash to dry when coated varied with the product and mixing ratio. Green slash in the sun, treated with primer at 1:1 ratio, dried to 20-percent moisture content in about 15 days; with RS-1, about 110 days; and with SS-1, 70 days. Slash samples treated with the waxes took up to 185 days to change to 20-percent moisture content.

DRY SAMPLES

It was premised that there would be relatively little change in moisture content of the dry samples over time except at rainfall periods (figs. 10, 11, and 12). The change in moisture of the treated and untreated samples as a result of these rainfall periods would be a measure of the effect of the protective coatings. To obtain positive changes in the moisture content of the slash samples as a result of the rain periods, we used moisture measurements taken before

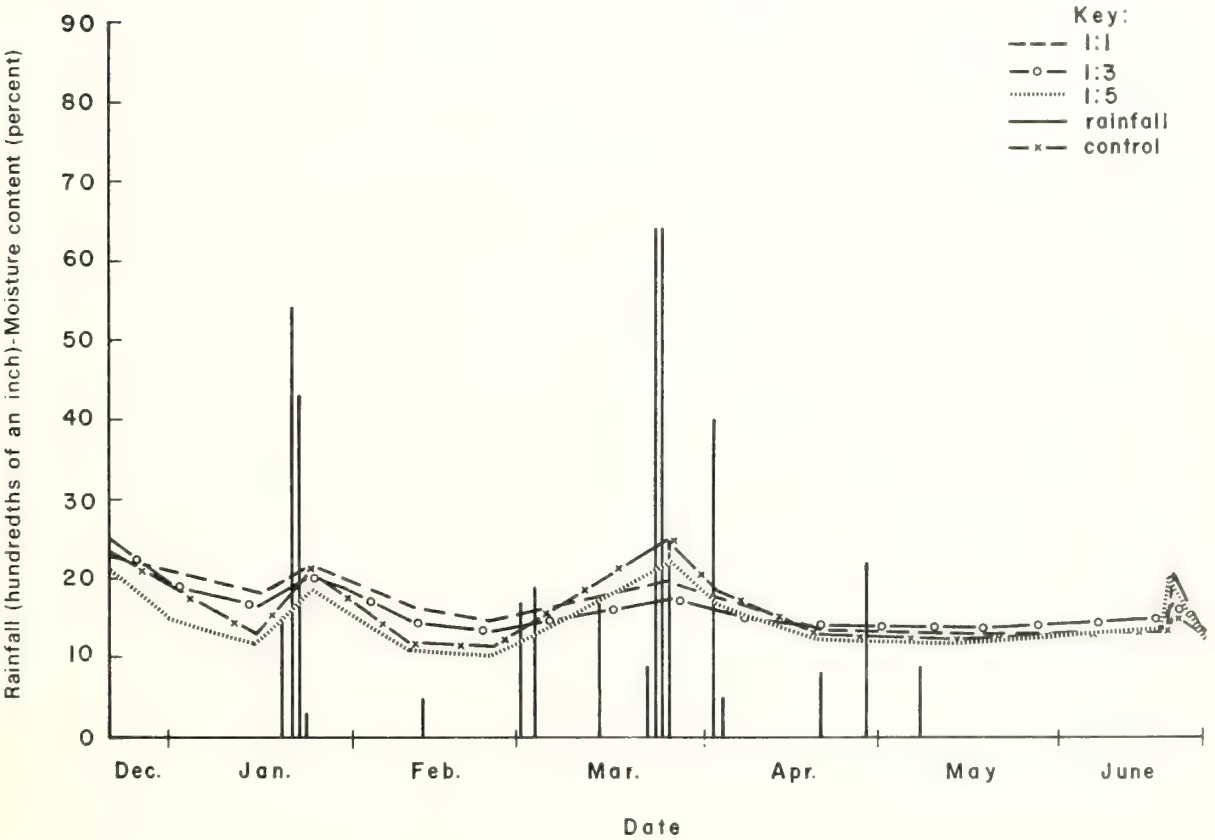

Figure 10.--Drying curves of dry slash treated with SS-1 at three mixing ratios in the sun environment.

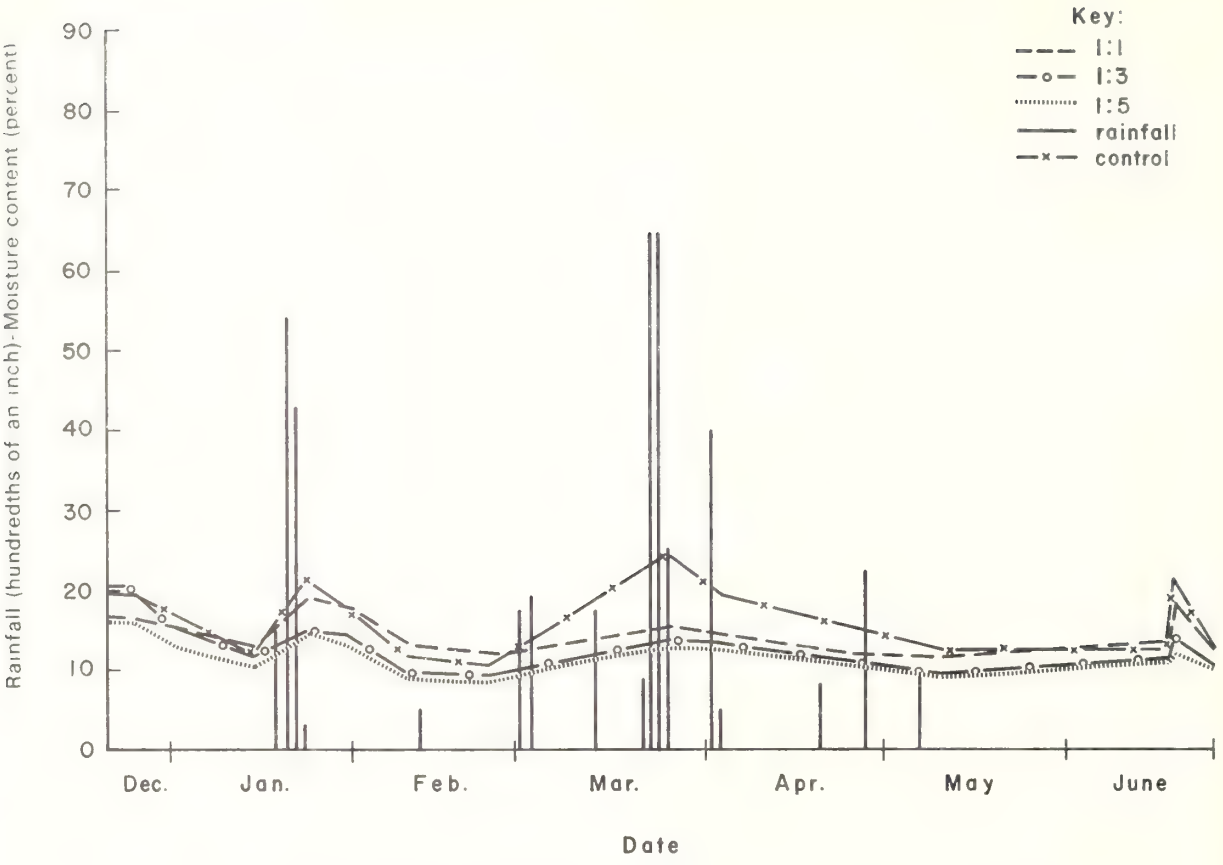

Figure 11.--Drying curves of dry slash treated with primer at three mixing ratios in the sun environment.

and just after each rainfall. "Before" measurements were taken 3 days before a rainstorm and "after" measurements the day following the storm. In almost all cases, the differences in moisture content between treated and control samples were greater after rain than before, indicating that the protective coatings were effective in keeping slash dry. Differences were less in shade than in sun. An analysis of variance showed that only some of these differences were significant, however.

The differences in moisture content of slash samples treated with SS-1 asphalt emulsion and the primer emulsion before and after rainstorms were significant at the 0.01-percent level for all three rain periods. Differences due to sun versus shade and concentrations were not significant for either product. The RS-1 asphalt coating provided no significant protection from rain at any concentration, in sun or shade. Study results pertaining to the effectiveness of the soil sealant and lumber waxes are of special interest. The differences in moisture content before and after rainstorms were significant at the 0.05- and 0.01-percent levels (three storms) for both products and all rainstorms. Concentration of the products significantly affected the differences

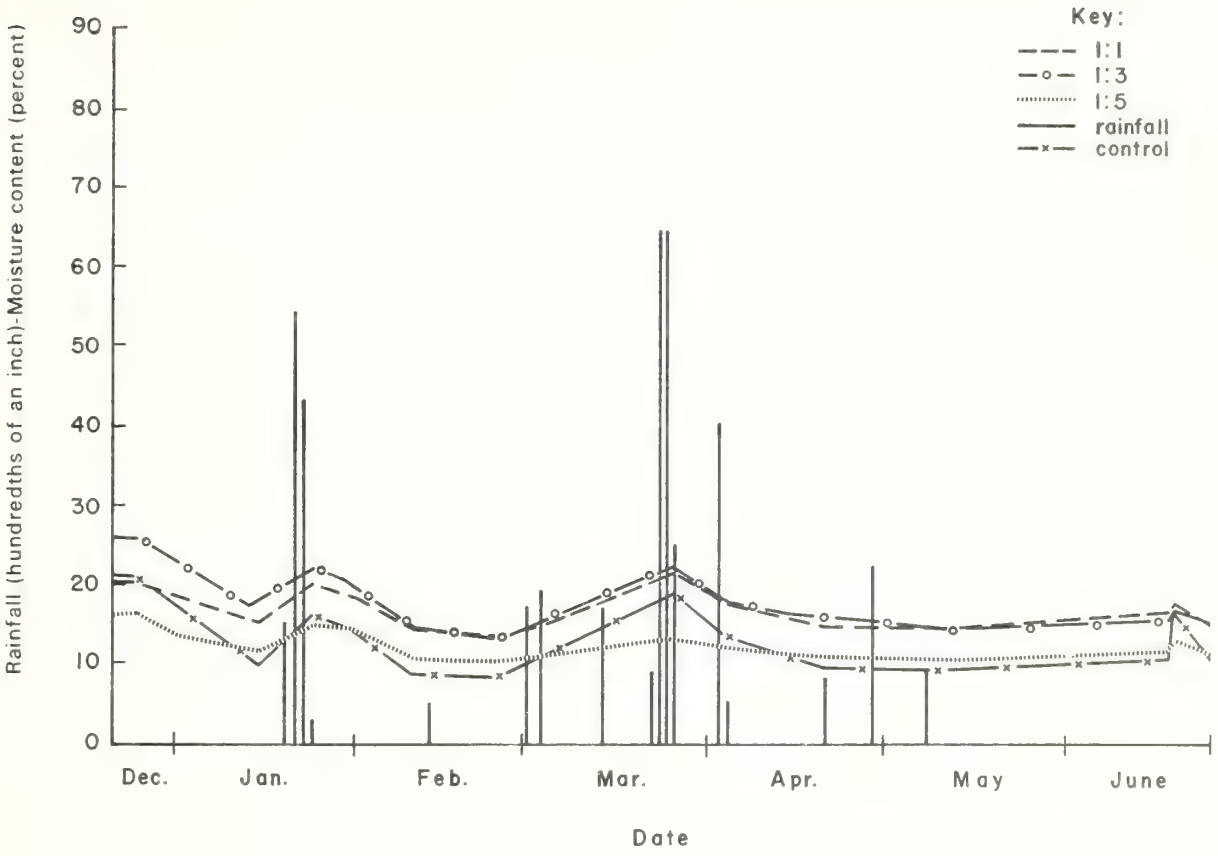

Figure 12.--Drying curves of dry slash treated with sealant wax at three mixing ratios in the sun environment.

before and after as a result of the January storm (0.05-percent level). In each case, there was a significant linear trend due to concentrations; that is, the greater the concentrations the smaller the difference and thus the greater the protective effect of wax coating. This was not true during the March and June storms, however, probably because the bark flaking and insect boring observed on all samples tended to reduce the effectiveness of the protective coatings at all concentrations. Samples treated with soil sealant wax and exposed to the sun showed significant differences (0.01-percent level) in moisture content before and after the June rainstorm. Differences due to interacting sun and rain were significant during the March storm for samples treated with lumber wax. The differences between treated and control samples exposed to the sun is especially interesting because weathering effects on the treated samples should be greater under sun (nonshade) conditions, especially at the later rain periods. The difference is not consistent enough, however, to necessarily indicate superiority of the waxes as protective coatings.

CONCLUSIONS

This study shows that RS-1, SS-1, wax (soil sealant), and lumber wax all retard the drying of green slash. Primer has very little effect on the drying of green slash. The drying times to reach 20-percent moisture content under the conditions of this test were extended by as much as 180 days by the wax coatings. The coatings also prevented the uptake of water during and after precipitation periods. The RS-1 and primer were as effective in this case as the other emulsions. The wax emulsions showed a significant relationship between concentration and fuel moisture. Apparently the primer and SS-1 can be used in more diluted form than the waxes for the same protection. This must be verified with field testing, however.

The SS-1, RS-1, and both waxes, when applied to green slash, would retard moisture loss. If green slash is created in spring or summer, this may mean the fuel hazard is decreased during the dry months but that fuel is still dry enough to burn during safe fall periods. Therefore, these coatings could be used on green slash if enough drying time before burning is available. On the other hand, primer can be applied to green slash without retarding drying, and it will provide protection from precipitation. This same objective might be accomplished with SS-1 at the lower concentration. Since the lower concentrations of waxes do not provide protection from precipitation, they should probably not be used on green slash except at high concentrations with long drying times.

In conclusion, there are differences between the effects of different water-repellent coatings on slash. The outstanding difference is between the primer and the four other emulsions. All coatings except RS-1 retarded the uptake of moisture by dry slash. Shade had a slight effect on moisture, generally slowing moisture loss. The most effective mixing ratio on drying retardation of green slash was 1:1. However, SS-1 and primer worked equally well in keeping slash dry at all ratios. There was a linear decrease in protection as the three water-mixing ratios were decreased. RS-1 had little effect in keeping slash dry and was hard to handle when diluted beyond 1:3.

Field testing should be the next step. Field studies should determine the differences between treatments that actually occur under natural conditions to provide guidelines for the use of selected coatings and their mixing ratios by forest-land managers.

Murphy, James L., Philpot, Charles W., and Garber, Morris J. 1969. The effect of asphalt and wax emulsions on moisture changes in slash. U.S.D.A. Forest Serv. Res. Pap. PNW-81, 14 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

A laboratory test was carried out to determine the relative effects of five different coatings on moisture content of ponderosa pine slash. Significant differences were found between effects of some of the coatings in both the retardation of drying in green slash and the moisture uptake by dry slash. Mixing ratios and shading had the greatest effect on drying rates and made little difference in water repellency. Field study is needed.

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SOME

EFFECTS OF CLEARCUTTING ON SALMON HABITAT

OF TWO SOUTHEAST ALASKA STREAMS

W.R. MEEHAN
W.A. FARR
D.M. BISHOP
J.H. PATRIC

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AUTHORS

William R. Meehan is Research Fishery Biologist, Institute of Northern Forestry, Juneau, Alaska.

Wilbur A. Farr is associate Research Mensurationist, Institute of Northern Forestry, Juneau, Alaska.

Daniel M. Bishop, formerly Hydrologist with the Institute of Northern Forestry, is now Watershed Scientist, Alaska Region, Forest Service, U.S. Department of Agriculture, Juneau, Alaska.

James H. Patric, formerly Research Hydrologist at the Institute of Northern Forestry, Juneau, Alaska, is now Project Leader, Watershed Management Research, Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Parsons, West Virginia.

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INTRODUCTION

A primary concern of land resource managers in southeast Alaska is the effect of timber harvesting on the fresh water environment of salmon. Salmon and timber are the two most important renewable resources in this region; they occur together — most of the watersheds that contain salmon streams also support commercial timber that will be harvested.

Spawning by adult salmon, as well as egg and fry survival, may be influenced by timber harvest which may change the quantity, regimen, and quality of streamflow or impair adult migration by obstacles originating on logged watersheds.

The economic importance of timber and associated forest resources, such as recreation and wildlife, is increasing with the expanding woodpulp market, improving access, growing population, and expanding tourism. The amount of timber harvested has about doubled in the last 10 years; the present rate is expected to nearly triple by the end of the next 10 years.[1] One aim of land management is to conduct this harvest in a manner that is compatible with salmon production.

Before the pulpmill at Ketchikan was completed in 1954, most logging had been concentrated in the better stands along beaches and nearby valley bottoms. Subsequently, large-scale logging expanded inland to valleys and adjacent slopes, beginning near Hollis on Prince of Wales Island. This harvest provided an opportunity to study logging effects on the physical characteristics of salmon spawning streams. James (1956)[2] has described the Hollis study area in considerable detail and discussed preliminary results obtained by the Alaska Forest Research Center (now the Institute of Northern Forestry). Since 1955, research has continued cooperatively with the U.S. Fish and Wildlife Service, Fisheries Research Institute of the University of Washington, and the Alaska Department of Fish and Game.

The original objective of this study, which began in 1949, was to determine if clearcutting and high-lead yarding affected salmon migration and spawning. As the study progressed, the environmental requirements of salmon in fresh water and the effect of clearcutting on watershed factors became better understood. Consequently, the objective gradually changed to the determination of the effect of clearcutting on the physical factors of salmon spawning streams.

This report summarizes the research and describes the main conclusions regarding the effect of clearcutting on streamflow,[3] suspended sediment, water temperature, and log debris.

LITERATURE REVIEW

Cordone (1956) and Chapman (1962) provided surveys of literature concerning logging effects on fish resources, with emphasis on studies from the western United States. Bullard (1950) summarized most of the earlier American research on forest watershed management. Our review will concentrate on more recent studies of physical effects of logging as evidenced by the quantity, regimen, and quality of streamflow. An exhaustive review of the literature is not attempted; rather, the present view of American forest hydrologists will be expressed in terms of recently published research findings. These findings highlight certain hydrologic principles that should be applicable in southeast Alaska.

---

[1] U.S.D.A. Forest Service. Annual statistics, 1916-1964. Region 10, Timber Business Records, 1967. (Unpublished report on file at Forest Service, U.S. Department of Agriculture, Juneau, Alaska.)

[2] Names and dates in parentheses refer to Literature Cited, p. 42.

[3] The hydrologic terminology used in this report is defined by Langbein and Iseri (1960).

However, they serve only as clues to quantitative relationships, because there is not a sufficient knowledge of southeast Alaska hydrology to provide a basis for adjusting results from other areas to local conditions.

STREAMFLOW

Quantity

> There can be little doubt that in most well-watered lands conversion of mature forest to low-growing vegetation will increase supply of water to streams. When considered independently of other factors, such as aspect, elevation, soil depth, and precipitation, first-year increases in yield seem roughly related to the percent of the fully developed stand that is removed or cut down. First-year increases in the order of 5-16 [area] inches may be expected at [the] Coweeta [Hydrologic Laboratory] after complete cutting of mature hardwood forests. Experiments of all types within the temperate zones of the world, neglecting Coweeta, suggest increases in streamflow up to about 10 [area] inches per year as a result of clearcutting forested watersheds, but the average would seem to be about half this amount. (Hewlett and Hibbert 1961.)

Increased streamflow following clearcutting has been documented in several subsequent studies. Rowe (1963) reported annual increases, depending on rainfall, ranging from 4.4 to 14.4 area-inches following removal of riparian woodland in California. Reinhart et al. (1963) reported increases of 1 to 5 inches following logging; the increased flows were roughly proportional to stand removal. For a tributary of Oregon's McKenzie River, Rothacher (1965) found 12 to 28 percent increased low flows following 30-percent vegetation removal, and an 85-percent increase following 80-percent removal. On an Arizona watershed, conversion of 80 acres of moist-site forest to grass increased streamflow about 55 percent (Rich 1965). Eschner and Satterlund (1966) reported a 7.72-inch decrease in annual streamflow between 1912 and 1950 when forest density notably increased on the Sacandaga River watershed in New York. Analysis of discharge measurements by Riggs (1965) for nine small streams in Virginia indicated that discharge per square mile was directly related to the percentage of the drainage basin cleared of trees and brush. Clearing land along channels seemed to produce a greater effect on discharge than clearing over the basin generally. This effect of clearing was most pronounced at extremely low levels of discharge and became negligible at high discharges.

Regimen

The rate of water absorption through the soil surface may be lower than the rate of water delivery to the surface; if so, some of the water delivered will flow upon the soil surface to streams (Colman 1953, p. 50). Little solid evidence is available that logging impairs the ability of soil to absorb water (i.e., causes surface runoff) except on roads and other areas of extreme disturbance.

On logged, nonroad surfaces, Steinbrenner and Gessel (1955) found a 34.9-percent average reduction in permeability, negligible change in bulk density, and an average porosity increase of 6.4 percent following tractor logging in Washington. Dyrness (1965) showed that tractor logging caused more soil surface disturbance (38 percent of the logged area) than high-lead logging (21 percent of the logged area). These authors implied that runoff rates increased following logging but did not demonstrate that infiltration rates were reduced below maximum rainfall rates.

Hoover (1944) and Kovner (1957) observed that no overland flow occurred on two clearcut watersheds in North Carolina. On these watersheds, the relationship of baseflow to stormflow remained unchanged several years after clearcutting (Dils 1957). Hewlett and Hibbert (1961) noted that overland flow was negligible at Coweeta except on watersheds abusively treated by overgrazing or farming. Peak flows in Oregon (Rothacher 1965) and southern California (Rowe 1963) were unaffected by logging. Reinhart et al. (1963) reported that augmented high flows followed heavy cutting during the growing season but that stormflows were unaffected by logging during dormant seasons. Here, the construction of roads contributed to storm runoff. Annual logging of less

than 6 percent of the Snow Creek basin in western Washington had no apparent effect on runoff (U.S. Geological Survey 1963).

Surface runoff is sharply reduced by revegetating damaged watersheds. Legumes planted on severely gullied land in South Carolina greatly reduced peak flows and stopped soil loss (Metz 1958). Two years after revegetation, stormflow on a mountain farm in North Carolina had returned nearly to preclearing levels (Dils 1957). Reforestation of the White Hollow watershed, Tennessee, reduced peak discharges 73-95 percent of levels observed before the area was reforested (Tennessee Valley Authority 1961). In Ohio, stormflow reductions following reforestation ranged from 52 percent in small storms to 84 percent in large storms (Hill 1960).

WATER QUALITY

Only the effects of logging on suspended sediment and stream temperature are considered in this review.

Suspended Sediment

The literature on suspended sediment in streams draining logged watersheds must be rigorously evaluated to determine damage due solely to roads (Packer 1966). Lieberman and Hoover (1948) showed that roads were the major sediment source during logging; their original notes (filed at Coweeta Hydrology Laboratory) implicitly state that the hydrologic functioning of nonroad surfaces was unimpaired by logging. Reinhart et al. (1963) observed that streamflow usually was clear on watersheds where road grades seldom exceeded 10 percent. Where most roads had 21- to 30-percent grades, stream turbidity of 5,000 parts per million (p.p.m.) was recorded. This sediment source became negligible 2 years after logging when roads had revegetated. When all roads were located away from streams and held below 10-percent grade, there was little increase in suspended sediment during logging (Black and Clark n.d.; Jones[4]). Rowe (1963) reported no detectable increase in erosion or storm peak discharges after clearcutting except from one or two minor washes along a newly constructed road. Statistical analysis showed no difference in mean annual sediment yields between logged and unlogged watersheds in Colorado (Leaf 1966). Anderson and Wallis (1963) presented equations for estimating sediment discharges from logged watersheds in Oregon and northern California but did not distinguish between cutover land and roads as sediment sources. About 2 percent of the Naselle River watershed, Washington, has been logged each year since 1921. Despite rainfall up to 51 inches per month and burning on 7 percent of the logged area, there has been no evidence of surface erosion (Martin and Tinney 1962). Watersheds supplying Seattle (Thompson 1960) and Oregon City (Horne 1960) were logged for several years with negligible damage to water quality.

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[4] Jones, Le Roy. A watershed study in putting a hardwood forest at the Coweeta Hydrologic Laboratory in the Southern Appalachian Mountains under intensive management. 1956. (Master's thesis on file at Univ. Georgia.)

Stream Temperature

The brief American literature on rise of stream temperature after logging is summarized in the following tabulation. Although stream temperature responses to logging varied greatly over the United States, they invariably occurred during midsummer.

Logging location	Maximum stream temperature increase (degrees F.)	Source of data
Lookout Creek tributary, Oregon	0	Oregon State Game Commission (1952, p. 278)
Maybeso Creek, Alaska	0	James (1957)
Rapid City, South Dakota	1	File data, Rocky Mountain Forest and Range Experiment Station
Franklin, North Carolina	4	File data, Southeastern Forest Experiment Station
Lookout Creek, Oregon	5	Oregon State Game Commission (1952)
Parsons, West Virginia	8	Reinhart et al. (1963)
Connecticut	10	Titcomb (1926)
Franklin, North Carolina	11.5	Greene (1950)
Glendora, California	16	File data, Pacific Southwest Forest & Range Experiment Station
Alsea River, Oregon	16	Hall (1967)

Reinhart et al. (1963) stated that " . . . dormant-season minimums were reduced on the average by 3-½° [F.]" on the clearcut watershed in West Virginia. A slight effect in the same direction was apparent on the Diameter Limit Watershed with no appreciable effects on Selection Watersheds. Hornbeck and Reinhart (1964) reported in addition that both maximum and minimum temperature differences from forest streams were reduced by half in the second year after logging.

LOG-DEBRIS JAMS

The damaging effects of large log-debris jams have been well documented, particularly in California and Oregon (California Department of Fish and Game 1955a, b, c; Corthell 1962). The most undesirable effects of large jams in salmon streams are blocking upstream salmon migration and causing excessive deposition and clogging of the streambed by sediment and debris.

Problems of jam obstructions and streambed sedimentation are particularly severe in the salmon streams of coastal Washington, Oregon, and California. All of the Pacific Coast States have codes or statutes that prohibit obstructing the passage of fish in a stream. These requirements have frequently proved inadequate (Calhoun and Seeley 1963). State fish and game departments generally favor leaving a vegetated strip next to streams. This has been incorporated into timber sales contracts in some areas (California Department of Fish and Game 1955c).

Much stream clearance and improvement work has been done in recent years. On the Coquille River of Oregon in 1960, $50,000 financed removal of 23 individual large jams and 5 miles of generally continuous jams on smaller tributary streams (Corthell 1962). On the north coast of California, 296 log jams on the Noyo River system were removed by State prison inmates; about 100 cubic feet of wood debris were removed per man-day (Holman and Evans 1964). In Alaska, Bishop[5] suggested an approach wherein the criteria for jam removal depend primarily upon stream gradient and streambed roughness.

In southeast Alaska, valleys tend to have a U-shape typical of recent glaciations. Valleys of the Pacific Coast Ranges tend to be V-shaped. Thus, problems of log-

[5] Bishop, D. M. Relationship between streambed pools and salmon spawning area in a southeast Alaska stream. 1964. (Unpublished report on file at Inst. North. Forest., Juneau, Alaska.)

debris jams differ. Jams in southeast Alaska are usually small and seldom obstruct migration. Measurments taken at two artificially built log jams near Hollis, Alaska, showed that the jams increased streambed movement and instability and reduced fine material content in the streambed (Helmers 1966). Intragravel dissolved oxygen may have been increased. Although the effect of small log-debris jams on salmon production remained undetermined, temporary or unstable jams were judged to be detrimental. Bishop[6] estimated that in the same stream, pools caused by log debris occupied about 10 percent of the streambed area, thus reducing available potential spawning area by a similar amount.

THE STUDY AREA

Location. — The study area, a part of the Tongass National Forest, is near Hollis, Alaska, on Prince of Wales Island, about 45 miles west of Ketchikan. It includes the Maybeso Experimental Forest (the entire Maybeso Creek drainage) and two adjacent watersheds, Harris River and Indian Creek (figs. 1, 2, 3, 4).

Climate. — Proximity of the Pacific Ocean holds both daily and seasonal temperatures within a narrow range. Daily fluctuations rarely exceed 15° F., and the mean monthly temperature ranges from near freezing in winter to about 60° F. in summer (Day 1921). Although the mountains are steep, few on this part of the island rise above 3,500 feet. Nevertheless, the rugged terrain has great effect on kind and amount of precipitation. Snow falls at Hollis between October and March. Snow accumulations greater than a foot are infrequent at sea level, but much more of the precipitation falls as snow in the mountains where patches often persist throughout the year. Since Hollis is in the path of storms moving east across the Gulf of Alaska, heavy precipitation (100 or more inches per year) and much cloudiness are the rule.

Although rainfall is greatest in the fall, intensity remains low, with 0.47 inch per hour the maximum recorded at Hollis. During a representative month, October 1953, measurable rain fell on all but one day at Hollis with a total of 20.32 inches; numbers of 1-hour periods having rain of specified intensity were:

Intensity (inches per hour)	Hours of rain
Trace to 0.05	356
0.06 to 0.10	67
0.11 to 0.15	48
0.16 to 0.20	11
0.21 to 0.25	3

Geology and soils. — Sedimentary rocks (graywacke, shale, black argillite, and conglomerate) predominate over the study area. Faulting, folding, and metamorphism have developed a considerable variety of bedrock structure and composition. The geology of Maybeso valley has been reported in detail by Swanston.[7] The region was extensively glaciated, resulting in oversteepened, unstable valley sides sometimes subject to landsliding (Bishop and Stevens 1964). Thus, most forest soils are derived from glacial or colluvial material on mountainsides or from alluvium in the valleys. Organic bog soils are common. Mineral soils usually are podzolized very gravelly or stony loams or silt loams containing a high proportion of gravel and stones. Many soils have rock or dense till substrata, but weathered horizons, ranging from 1 to 3 feet deep, are very porous and highly permeable. All soils are covered with litter, moss, and permanently moist duff ranging from 5 to 12 or more inches deep. Soil profile development is

[6] See footnote 5.

[7] Swanston, Douglas N. Geology and slope failure in the Maybeso valley, Prince of Wales Island, Alaska. 1967. (Unpublished doctoral thesis on file at Department of Geology, Mich. State Univ., East Lansing.)

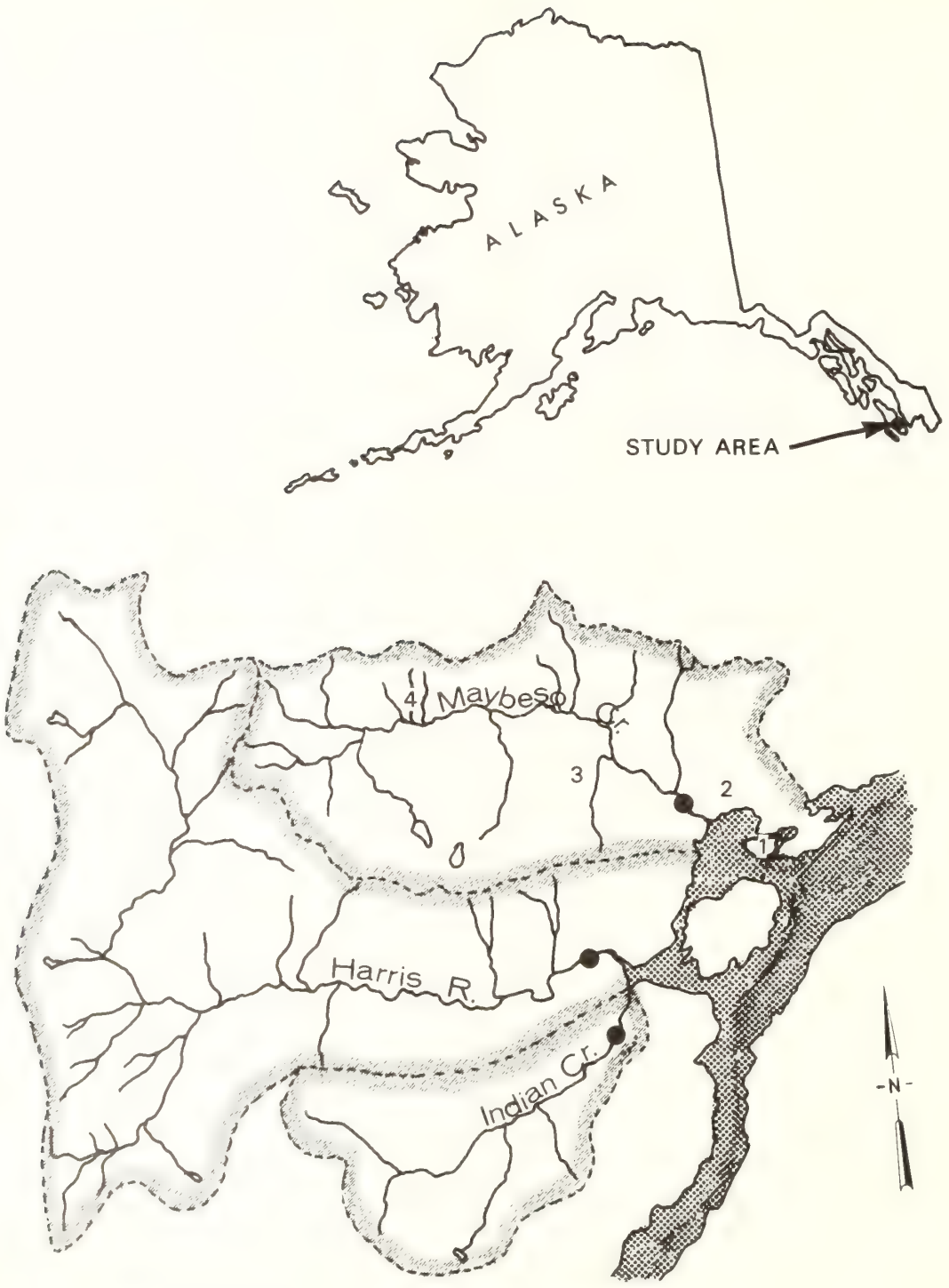

Figure 1—*Map of three gaged watersheds near Hollis, Prince of Wales Island, Alaska.*

Figure 2 — *Maybeso Creek watershed, Prince of Wales Island, Alaska, 1961.*

Figure 3 — *Harris River watershed, Prince of Wales Island, Alaska, 1961.*

Figure 4 — *Indian Creek watershed, Prince of Wales Island, Alaska, 1961.*

Figure 5 — *A productive forest soil commonly found in the study area, Hollis, Alaska (scale in feet).*

deeper and more pronounced at lower elevations. The study area soils have been mapped and described by Gass et al. (1967). A typical forest soil profile is shown in figure 5.

Forests. — The study area was densely forested with western hemlock *(Tsuga heterophylla* (Raf.) Sarg.), Sitka spruce *(Picea sitchensis* (Bong.) Carr.), Alaska-cedar *(Chamaecyparis nootkatensis* (D. Don) Spach), and western redcedar *(Thuja plicata* Donn.) comprising 76, 20, 2, and 2 percent of the stand, respectively. Stands of commercial value usually grew at elevations below 1,500 feet and occupied about one-third of the watershed area. Nonforested bogs occupied about one-sixth of the land area, the balance being noncommercial forest, alpine meadow, and rock outcrop (Gass et al. 1967). Godman (1952) has described in considerable detail the composition of old-growth forests typical of southeast Alaska.

Watershed characteristics. — The description in table 1 is drawn primarily from James (1956), who previously discussed the study area streams.

Fish. — Pink salmon *(Oncorhynchus gorbuscha* (Walbaum)) and chum salmon *(O. keta* (Walbaum)) are the major species maintaining spawning populations in the study streams. Coho salmon *(O. kisutch* (Walbaum)) occur in smaller numbers, and a few sockeye salmon *(O. nerka* (Walbaum)) are observed in some years. Harris River and Maybeso Creek also support populations of steelhead trout *(Salmo gairdneri* Richardson).

Table 1—*Some characteristics of watersheds near Hollis, Alaska*

Characteristic	Maybeso Creek	Harris River	Indian Creek
Main channel gradient . . . . . percent	0.86	0.30	1.0
Main channel length . . . miles	5.8	10.9	3.2
Watershed area acres	9,728	20,352	5,504
Area logged . . . . . acres	2,472	4,025	0
Area logged . . . . . percent	25.4	19.8	0
Merchantable timber MM bd. ft.	131.4	221.7	28.3
Peat land and organic soil percent	15	19	37
Orientation . . . . . direction	ESE.	S. and E.	NE.
Maximum elevation . . . . feet	3,392	3,806	2,267
Average rate of discharge[1] c.f.s.[2]	136	256	86.1
Maximum stormflow c.f.s.m.[3]	249	307	905
Minimum streamflow c.f.s.m.	.60	.35	.22

[1] 1949-64 (U.S. Geological Survey 1965, pp. 35-81).
[2] Cubic feet per second.
[3] Cubic feet per second per square mile.

METHODS

Timber harvesting by the clearcutting method began above the stream gaging station in Maybeso valley in 1953 and ended in 1957. The Harris River valley was harvested by the same method in 1959-61. Clearcutting is an efficient method of harvesting mature stands and of preparing the sites for growing new stands. The extent of clearcutting can be approximated from figures 2 and 3. High-lead logging was used on most of the area; some of the flatter valley bottoms were logged with tractors.

Logging roads in the valley bottoms were constructed by laying crushed rock and gravel over the undisturbed forest floor where road grades seldom exceeded 5 percent. These roads ordinarily were located several hundred feet from major stream channels, well outside the 50- to 100-foot minimum spacing between road and creek recommended by Trimble and Sartz (1957). Valley-side roads were excavated full width, then covered with crushed rock and gravel. Grades on these roads seldom exceeded 15 percent; water drained into inside ditches and crossed under roads through log culverts. All streams were crossed at about right angles with log bridges. After logging, bridges and culverts were removed from abandoned roads, and cross-drain ditches were installed.

Climatic data were collected at four stations in the study area (fig. 1). The following tabulation summarizes, for each station, the types of data obtained and the period of record. Recording gages were used at all stations except at Maybeso bog where monthly precipitation was measured in an 8-inch U.S. Weather Bureau standard gage.

	Period of operation	Climatic factors measured
Weather station:		
Hollis[1]	1949-62, year around	Temperature Precipitation
Fire weather station	1957-61 May to October	Relative humidity Temperature Precipitation Wind
Maybeso bog	1953-60 May to October	Precipitation
Upper Maybeso	1958-61 May to October	Precipitation

[1] From 1949 to 1962, summer (May-October) weather observations were made at Cat Island; from 1953 to 1962, winter (October-May) records were maintained at the Hollis logging camp, approximately 0.7 mile northwest of the Cat Island weather station.

Water levels were recorded from 1949 to 1964 on strip chart instruments at Harris River and Maybeso and Indian Creeks. Gaging sites for these streams were chosen at bedrock sections close to tidewater. For each gaging section, stage-discharge curves were developed by use of a current meter. Gaging stations were serviced as often as possible, but visits sometimes were a month or more apart at this remote location.

A thermometer component of the water stage recorder provided most of the temperature data from each gaged stream. The thermometer bulb was placed as close as possible to midchannel and just under the gravel surface in Maybeso and Indian Creeks. The thermometer bulb in Harris River was on bedrock. In addition, a mercury thermometer provided checks of recorded temperature during service visits to the stream gaging stations.

Suspended sediment was sampled occasionally in each stream from 1950 to 1963 and at weekly intervals and during stormflows in the summer and fall of 1960 and 1961. In periods of low flow, suspended sediment was sampled with a USDH 48 hand sampler (fig. 6); a larger cable-suspended sampler was used during high flows. Total organic and inorganic content were measured by the Gooch Crucible Technique (American Public Health Association 1962, p. 327) by use of commercially prepared crucible filters.

Until 1960, log-debris jams in the study streams were mapped annually on base maps prepared by planetable in 1949. After 1960, large-scale aerial photography (about 1:1,800) was used to reduce mapping time and to increase accuracy. Logs, chunks, and stumps were counted individually, except in large jams where estimates were necessary.

Since 1948, annual aerial and ground surveys by various agencies concerned with fish populations have provided estimates of salmon escapement to the study streams; i.e., the numbers of spawners escaping fishermen and other offshore hazards to reach the spawning beds.

Figure 6 — *Sampling suspended sediment with a USDH 48 sampler.*

Table 2 summarizes 13 years of climatic data from the Hollis weather station; daily and monthly values have been published by the U.S. Weather Bureau (1952-63). Monthly rainfall at Hollis and at three other locations in the Maybeso valley (fig. 1) are summarized in table 3. These data show that, on the average, more rain falls upvalley than at Hollis. For the period of record, the Maybeso bog location received about 20 percent and the upper Maybeso location about 26 percent more summer rainfall than was recorded at Hollis. The fire weather station and Hollis received similar amounts of rainfall.

Figure 7 compares the rainfall catch at Maybeso bog with coincident gage catch at Hollis for 62 storms. Distribution of points about the 1:1 line (denoting equal rainfall distribution) suggests that rainfall within the watershed varies greatly between storms even though, on the average, more rain falls upvalley.

Table 2—*Average monthly climatic data for Hollis, Alaska, 1952-64*

Month	Precipitation	Temperature	Potential evapotranspiration[1]
	Inches	Degrees F.	Inches
January	9.64	32.4	0
February	9.07	34.4	0.23
March	6.90	36.2	.61
April	7.59	40.7	1.38
May	4.53	48.0	2.79
June	4.27	54.0	3.67
July	3.30	58.5	4.11
August	5.16	58.0	3.75
September	7.95	52.1	2.54
October	18.69	36.9	.46
November	13.01	36.9	.46
December	13.47	34.4	.21
Annual	103.58	44.2	20.21

[1] Thornthwaite and Mather (1957).

Table 3—*Total monthly rainfall at four locations in the Maybeso Experimental Forest, Prince of Wales Island, Alaska, 1953-61*

Date	Hollis (Cat Island)	Fire weather	Maybeso bog	Upper Maybeso
		Inches		
1953:				
June	1.77	—	(1)	—
July	2.21	—	(1)	—
August	5.49	—	6.81	—
September	10.44	—	(1)	—
October	20.32	—	—	—
1954:				
June	2.86	—	3.09	—
July	2.95	—	3.20	—
August	.42	—	.57	—
September	5.48	—	7.09	—
October	16.17	—	19.40	—
1955:				
June	3.21	—	5.53	—
July	.91	—	.89	—
August	7.14	—	9.30	—
September	8.28	—	10.15	—
October	16.20	—	—	—
1956:				
June	2.91	—	3.46	—
July	1.73	—	2.10	—
August	9.15	—	11.03	—
September	4.53	—	22.70[3]	—
October	15.98[2]	—		—
1957:				
June	5.67	5.73	5.69	—
July	3.24	2.98	4.00	—
August	3.26	3.12	3.88	—
September	6.09	6.59	7.53	—
October	—	—	—	—
1958:				
May	6.88	6.89	8.48	10.40
June	.56	.53	.58	.45
July	2.99	2.94	3.68	3.11
August	5.77	(1)	7.31	7.87
September	7.33	(1)	8.29	9.94
October	—	—	—	—
1959:				
May	3.60	(1)	5.33	5.40
June	5.12	(1)	5.51	5.49
July	6.06	(1)	7.22	7.59
August	3.91	(1)	4.87	6.57
September	7.90	(1)	8.78	10.03
October	13.90	—	—	—
1960:				
May	4.31	4.36	4.38	5.15
June	4.73	4.47	6.73	6.70
July	3.79	3.02	3.24	5.21
August	4.93	4.83	5.45	4.81
September	7.85	8.06	8.70	12.02
October	22.31	—	24+	25.57
1961:				
May	2.87	2.73	—	3.42
June	4.03	3.86	—	6.30
July	2.67	2.69	—	3.02
August	5.32	5.53	—	7.41
September	8.65	9.09	—	10.29
October	32.26[4]	—	—	21.30[5]

[1] Data incomplete.

[2] Total rainfall between October 1 and 25, 1956 = 14.04 inches.

[3] Total rainfall for the period September 1 to October 25, 1956.

[4] Total rainfall between October 1 and 16, 1961 = 21.16 inches.

[5] Total rainfall for the period October 1 to 16, 1961.

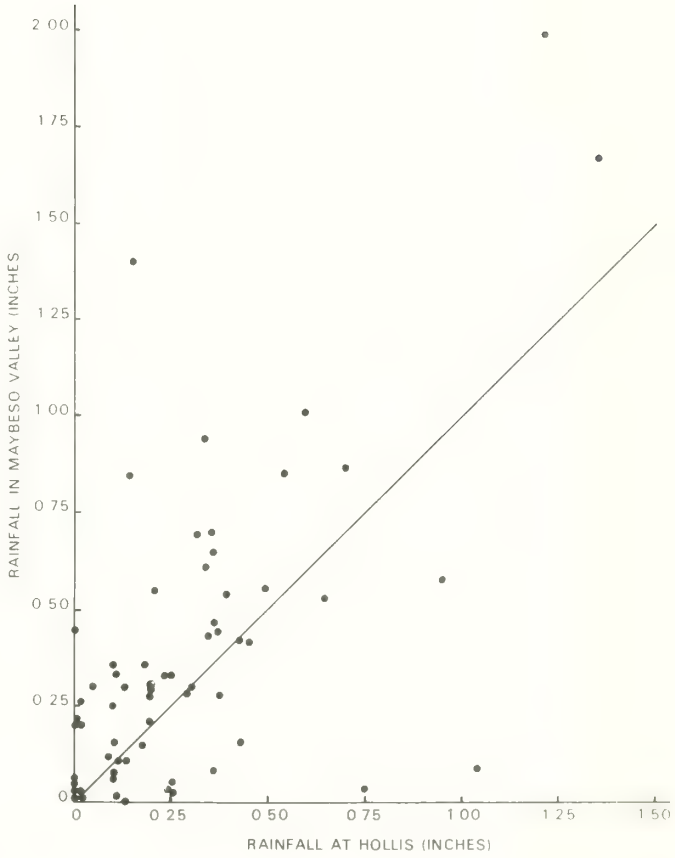

Figure 7 — *Comparison of rainfall at the Maybeso bog station with coincident rainfall at Hollis, Alaska, weather station during the summer of 1953. The 1:1 line denotes equal rainfall distribution.*

RESULTS

STREAMFLOW

Daily flows from the gaged watersheds have been published by the U.S. Geological Survey (1965). Annual precipitation at Hollis and flow data for the study streams are summarized in table 4. These summaries also show that watershed precipitation was greater than sea level precipitation recorded at Hollis, a situation characteristic of hydrologic data from southeast Alaska (Federal Power Commission and U.S.D.A. Forest Service 1947) and more recently observed near Hollis by Walkotten and Patric (1967).

Figure 8 shows the highest, average, and lowest streamflows recorded for the study streams. Snowmelt caused high flows in April and May; those in October were caused by heavy rain. Declining peak and average streamflows in November reflect reduced precipitation. Frequent rains and rapid snowmelt probably caused the high flows in December and January. These streams have low midsummer flows, typical of other streams of the region that are not glacially fed. Very low summer flows in Indian Creek may be related to the high proportion of bog soils in its headwaters.

Double mass plotting (Searcy and Hardison 1960) of water yield (fig. 9) indicates no evident increase of streamflow following clearcutting.

Figure 10 compares rainfall at Hollis with associated increases in the discharge of Harris River, before and during clearcutting. Covariance analysis of data before vs. during clearcutting indicated no significant influence of this treatment on stormflow regimen. A small nonsignificant decrease in peak flows during clearcutting, as shown in figure 10, can be attributed to one very high discharge value before clearcutting.

Table 4—*Annual precipitation and runoff at Hollis, Alaska, 1950-64*

Annual precipitation (year and inches)	Runoff		
	Maybeso Creek	Harris River	Indian Creek
	— — — — Area-inches[1] — — — —		
1950	(2)	110.11	101.48	101.0
1951	(2)	92.93	95.31	96.42
1952	81.72	132.84	118.98	126.87
1953	(2)	141.76	126.31	153.08
1954	84.45[3]	131.89	119.54	118.17
1955	(2)	114.77	113.30	133.87
1956	102.73	133.32	119.10	139.02
1957	72.51	82.57	81.35	86.30
1958	100.58	124.59	129.50	141.32
1959	117.61	149.86	146.50	145.81
1960	106.74	132.75	134.99	167.04
1961	118.05	113.28	136.86	141.91
1962	101.01	133.37	126.23	161.37
1963	(2)	(2)	128.38	139.58
1964	(2)	—	—	—

[1] Depth to which the watershed area would be covered if all the runoff for a given year were uniformly distributed on it.

[2] Incomplete data.

[3] December missing.

WATER QUALITY

Suspended Sediment

Figure 11 compares sediment in water samples obtained from Harris River before, during, and after clearcutting. The basic data (table 5) were transformed to logarithms, and this transformation was fairly successful in equalizing variances about regression.

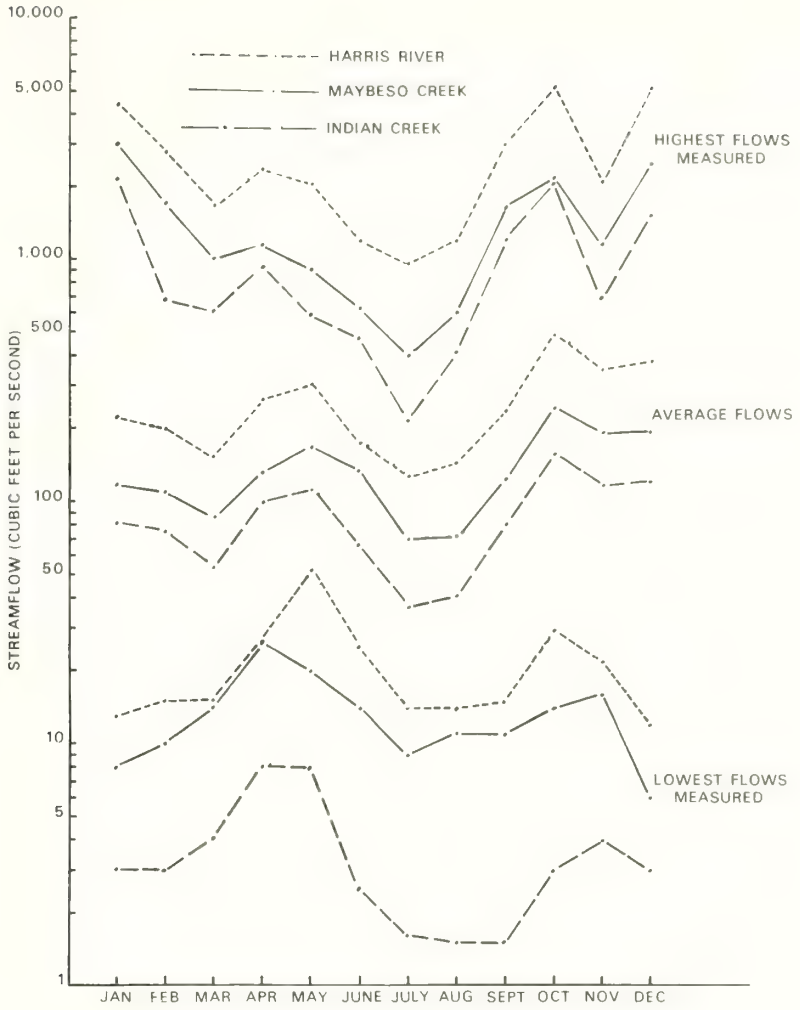

Figure 8 — *Monthly average flow of three gaged streams near Hollis, Alaska, 1949-64.*

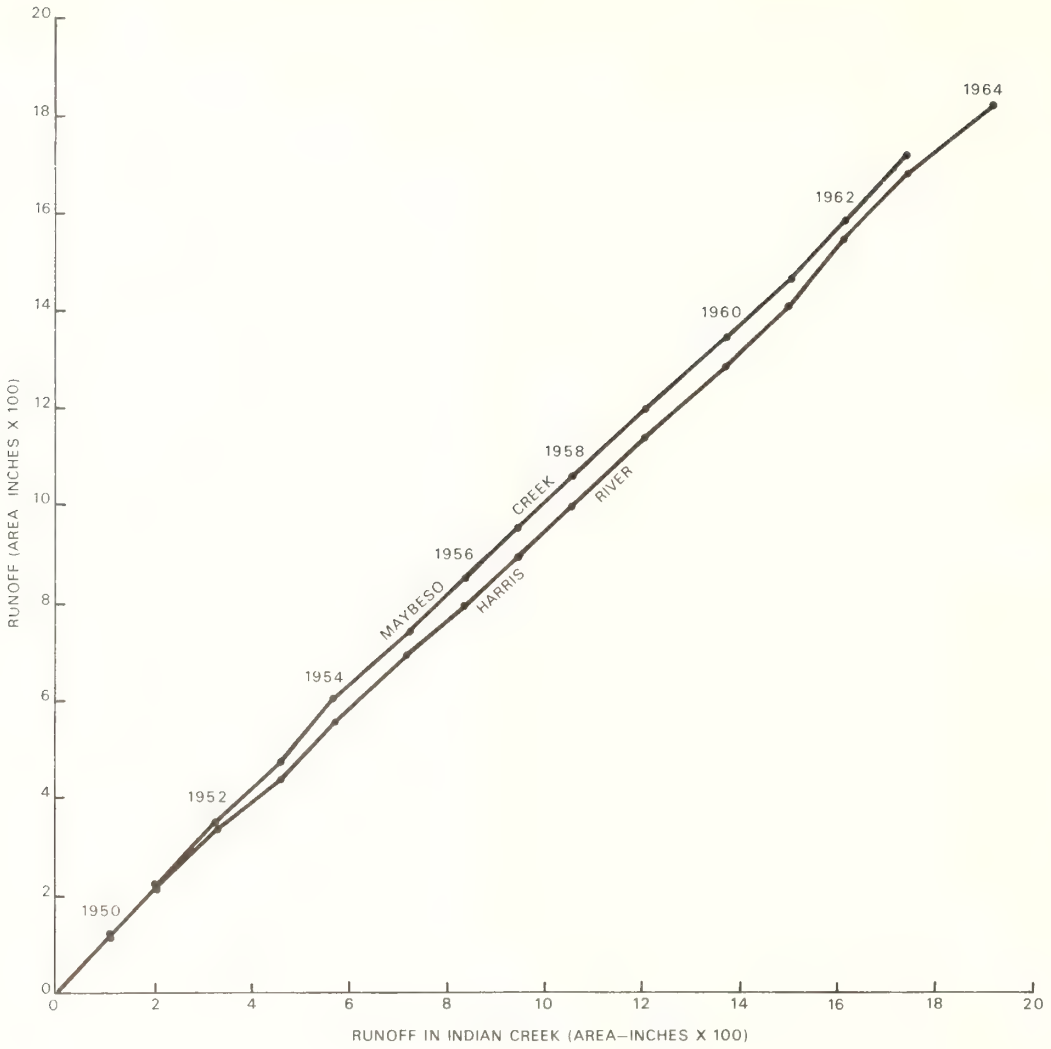

Figure 9 — *Double mass curves of runoff from Harris River and Maybeso Creek vs. Indian Creek, Prince of Wales Island, Alaska, show no departures from a linear relationship that can be attributed to clearcutting.*

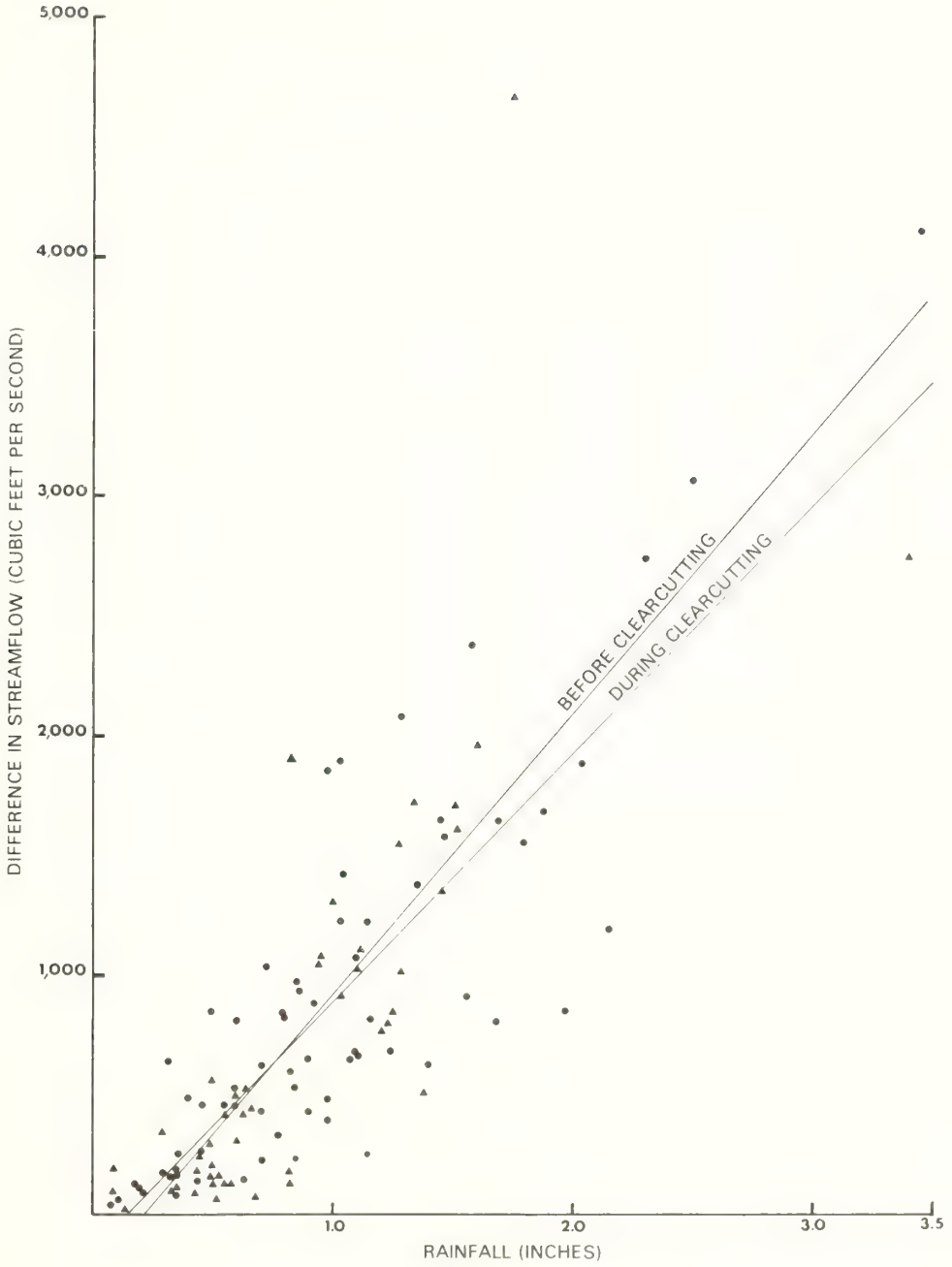

Figure 10 — *Stream discharge response to rainfall in Harris River, Prince of Wales Island, Alaska, before and during clearcutting.*

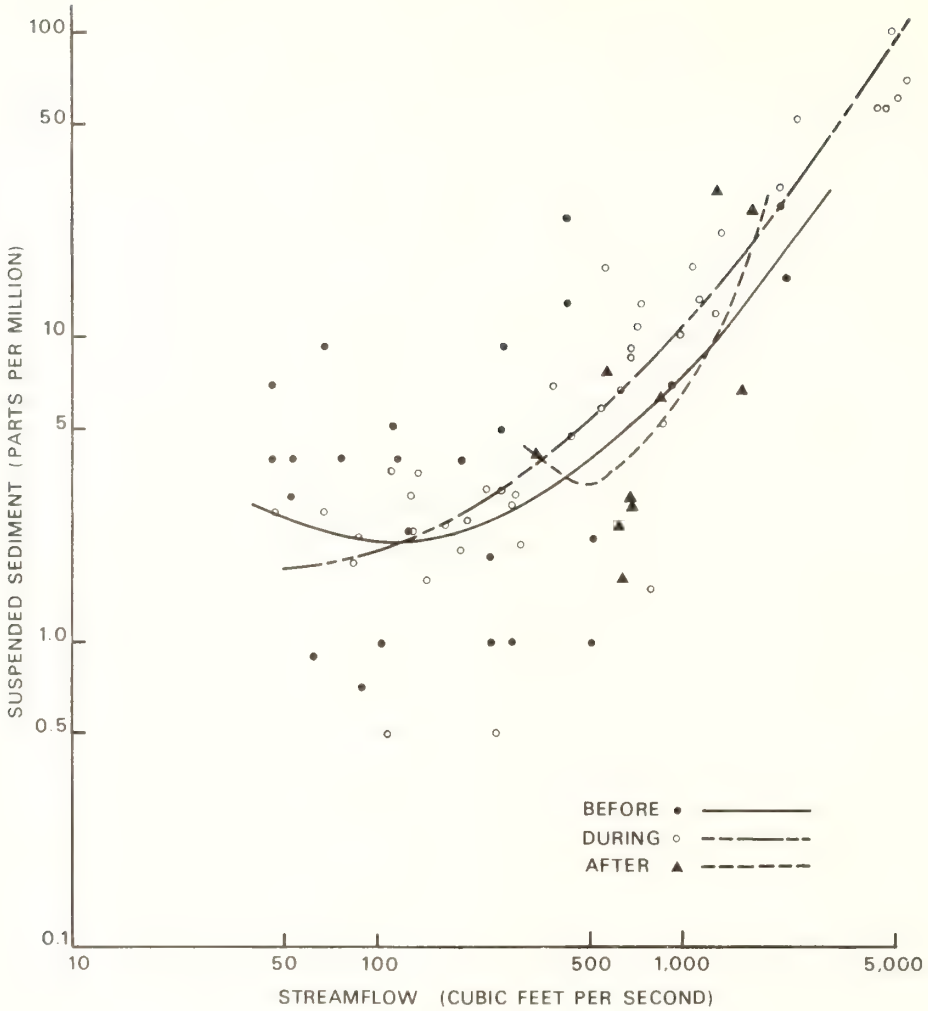

Figure 11 — *Suspended sediment in Harris River, Prince of Wales Island, Alaska, before, during, and after clearcutting.*

Table 5—*Water level, discharge, and suspended sediment measurements; Harris River, Prince of Wales Island, Alaska, 1955-63*

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	— — — Ppm — — — —		
1955:						
June 9		—	—	1.0	0	1.0
August 12		—	—	1.0	0	1.0
1956:						
May 22		2.97	548	1.0	0	1.0
June 19		2.19	278	1.0	0	1.0
August 20		3.70	905	7.0	4.0	3.0
1957:						
—		1.00	45	4.0	0	4.0
—		1.00	45	7.0	—	—
—		1.00	45	7.0	—	—
—		2.01	232	1.0	0	1.0
—		1.38	103	1.0	—	—
—		1.83	189	4.0	1.0	3.0
—		1.52	128	3.0	0	3.0
—		1.05	52	3.0	0	3.0
—		1.05	52	4.0	—	—
—		1.22	76	4.0	—	—
—		1.22	76	4.0	—	—
—		1.46	117	4.0	—	—
—		2.61	414	13.0	7.0	6.0
—		2.61	414	25.0	17.0	8.0
—		1.48	120	5.0	—	—
—		2.08	250	5.0	1.0	4.0
November 13		2.00	230	1.9	—	—
December 27		1.10	58	0	0	0
1958:						
January 8		1.90	205		—	—
February 24		1.70	161	0	0	0
May 13		5.35	2,115	16.0	0	16.0
June 12		1.08	55	0	0	0
July 22		1.12	61	.9	0	.9
July 27		1.30	89	.7	—	—
July 31		2.10	255	9.3	3.3	6.0
August 7		2.29	307	0	0	0
August 13		1.15	66	0	0	0
August 13		1.15	66	9.3	1.3	8.0
August 20		2.85	500	2.2	0	2.2
September 17		1.50	124	2.3	—	—
1959:						
May 27		2.10	255	3.1	—	—
June 9		2.07	248	2.0	—	—
June 29		1.57	137	3.6	—	—
July 14		2.99	556	17.0	—	—
July 20		2.04	240	4.4	—	—
July 26		1.53	129	2.3	—	—
August 20		1.28	86	2.2	—	—
September 8		3.43	785	1.5	—	—
September 11		3.10	605	6.8	—	—
September 24		1.83	189	2.0	—	—
December 4		3.60	850	5.2	3.3	1.9
1960:						
July 1	1000	1.61	144	1.6	.1	1.5
July 11	1115	1.73	167	2.4	1.0	1.4
July 12		2.25	295	2.1	1.2	.9
July 18	1620	1.87	198	2.5	.7	1.8
July 25		1.41	108	.5	0	.5

See footnote at end of table.

Table 5—*Water level, discharge, and suspended sediment measurements; Harris River, Prince of Wales Island, Alaska, 1955-63*—Continued

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	— — — — P.p.m. — — — —		
1960 (cont.):						
August 1		1.15	66	2.7	.1	2.6
August 8		1.02	48	2.7	0	2.7
August 15		1.26	83	1.8	0	1.8
August 22	1000	—	—	.6	0	.6
August 29	1000	—	—	2.7	.2	2.5
September 6	0935	—	—	2.0	.7	1.3
September 12	1530	1.42	110	3.7	3.1	.6
September 22		2.94	536	6.0	2.8	3.2
September 22	0800	3.37	730	13.0	6.5	6.5
September 22	0845	3.25	672	8.8	6.5	2.3
September 23		3.26	677	8.6	7.3	1.3
September 26		2.05	242	2.0	.4	1.6
October 3		2.05	242	.5	0	.5
October 5		4.05	1,110	13.5	6.8	6.7
October 5		4.35	1,315	22.1	12.1	10.0
October 6		3.80	960	10.2	6.6	3.6
October 6		4.00	1,080	17.2	5.3	11.9
October 6		4.31	1,287	12.1	7.3	4.8
October 9		5.26	2,034	31.9	19.3	12.6
October 10		5.58	2,322	53.1	36.3	16.8
October 17	1030	1.99	228	3.2	.2	3.0
October 24		2.17	272	2.8	1.2	1.6
October 27		3.27	682	9.4	2.4	7.0
October 27		3.34	715	11.0	5.3	5.7
1961:						
August 25		2.20	280	3.1	1.0	2.1
August 28		2.68	438	4.8	3.9	.9
August 30		2.47	364	7.0	3.3	3.7
September 17		3.39	740	13.0	5.9	7.1
October 2		6.82	3,602	148.7	110.7	38.0
October 3		5.50	2,070	27.2	18.7	8.5
October 14	1020	8.50	5,300	70.9	54.5	16.4
October 14	1055	8.00	4,940	61.4	47.2	14.2
October 14	1110	7.90	4,820	101.5	84.8	16.7
October 14	1125	7.70	4,580	58.3	42.6	15.7
October 14	1220	7.45	4,280	58.7	39.9	18.8
1962						
September 23		4.78	1,634	26.5	18.3	8.2
October 6		3.57	834	6.3	.3	6.0
October 16		3.10	605	2.4	.9	1.5
1963:						
September 24		4.30	1,280	30.1	—	—
October 10		2.31	313	4.2	2.3	1.9
October 12		3.16	632	1.6	.3	1.3
October 12		3.27	682	2.8	.9	1.9
October 14		3.00	560	7.8	2.8	5.0
October 19		4.65	1,530	6.8	3.5	3.3
October 28		3.22	659	3.0	.1	2.9

[1] Specific dates up to November not available for 1957.

Covariance analysis was used to test the hypothesis that regression coefficients and adjusted means were not changed by clearcutting. The covariance analysis forced us to choose a single equation form; a quadratic form was chosen since one of the three relationships was quadratic. Graphical solutions to the three quadratic equations are shown in figure 11. The drastic curvature at the lower end of the "after logging" curve is at the limit of the actual data.

Two covariance tests were made: the first with all three groups of data (before, during, and after), and the second for the two groups before and after. There was no evidence in either test of a difference between regression coefficients or adjusted means. It appears, therefore--based upon this limited sample--that logging did not significantly affect the relationship between suspended sediment and streamflow in Harris River.

Samples from Maybeso Creek (table 6), though fewer in number, indicated lower suspended sediment levels than in Harris River (table 5). It is evident that suspended sediment in all of these streams has remained at low levels throughout the period of record (see also table 7).

Suspended sediment was sampled in Harris River while logs were being yarded across the streambed[B]. Water samples from one-fourth mile above this operation averaged 3.7 p.p.m. suspended sediment; samples obtained one-half mile downstream averaged 9.7 p.p.m.

Stream Temperature

Stream temperature was highly correlated with air temperature and time of year. As shown in the comparison of monthly averages (fig. 12), streams warmed more slowly in the spring and cooled more slowly in the fall than did the air. Average air temperature was highest in July, and average stream temperature was highest in August.

Temperature differences between streams also were apparent. Indian Creek, the smallest stream, tended to be colder than the other study streams in springtime but responded more quickly to increasing air temperature and was warmer than the others from June to September. This character is probably due to differences between the watersheds (table 1). Temperatures of Maybeso Creek and Harris River were similar throughout the year.

A 10-year record for Indian Creek, in the unlogged watershed, showed considerable variation in year-to-year average monthly stream temperatures (fig. 13). Temperatures of Harris River and Maybeso Creek also showed similar differences before logging. Tables 8, 9, and 10 give the complete summary of maximum, average, and minium monthly temperatures for all three study streams. Table 11 (which was prepared from the average monthly stream temperatures presented in tables 8, 9, and 10) shows the year-to-year variation in stream temperature differences.

Maximum Stream Temperatures

Daily temperatures of all streams often exceeded 60° F. during the months of June, July, and August (tables 5, 12, 13, 14, 15, and 16). Average monthly temperatures exceeded 50° F. only during the months of June to September. An average monthly stream temperature of 60° F. or greater was recorded only during the exceptionally warm month of July 1958.

Stream Temperature Changes Due to Logging

Increases in stream temperatures were detected on both logged watersheds after certain operations (table 11). Winter stream temperatures at the gaging sites showed little, if any, change.

[B] Yarding across the stream was observed once in Harris River and once in Maybeso Creek.

Table 6—*Water level, discharge, and suspended sediment measurements; Maybeso Creek, Prince of Wales Island, Alaska, 1957-63*

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	— — — — P.p.m. — — — —		
1957:[1]						
		1.56	85	2.0	0	2.0
		1.40	63	3.0	0	3.0
		1.43	67	2.0	—	—
		1.30	51	4.0	—	—
		.95	20	2.0	0	2.0
1958:						
January 30		1.57	86	0	0	0
May 9		1.86	132	0	0	0
May 14		4.66	1,100	8.9	0.5	8.4
June 4		1.57	86	2.4	—	—
June 10		1.21	41	.3	—	—
July 24		.90	17	1.1	0	1.1
July 31		1.38	61	2.4	—	—
August 5		2.93	360	6.4	1.0	5.4
August 14		1.45	69	.6	0	.6
September 15		1.00	23	0	0	0
1959:[1]						
		2.30	219	2.5	—	—
		1.64	196	0	—	—
May 18		1.86	133	1.8	0	1.8
May 27		2.16	189	2.2	—	—
June 4		3.18	454	6.8	4.0	2.8
June 30		1.40	63	1.4	—	—
July 15		1.95	149	2.8	—	—
July 20		1.64	96	2.4	—	—
July 26		1.64	96	3.0	.3	2.7
August 3		1.95	149	2.4	—	—
August 24		1.19	39	5.2	0	5.2
September 8		1.27	48	1.4	—	—
September 18		1.25	46	3.1	—	—
September 24		1.58	87	1.7	—	—
September 25		3.98	737	24.0	16.1	7.9
1960:						
July 1	0830	1.65	99	1.1	.1	1.0
July 11	1010	1.52	79	.4	0	.4
July 12	0850	2.00	160	2.6	1.0	1.6
July 18	1705	1.58	87	2.3	1.4	.9
July 26		1.30	51	.5	0	.5
August 1		1.18	39	1.7	.6	1.1
August 15		1.33	55	18.5	10.5	8.0
August 18	2200	1.95	149	3.9	.8	3.1
August 22		1.30	51	5.6	3.7	1.9
August 29	0935	1.60	90	2.1	.3	1.8
September 12	1500	1.32	53	1.8	1.1	.7
September 19	1130	1.51	53	5.0	2.6	2.4
September 26	0915	1.71	107	2.1	.1	2.0
October 3		1.72	107	.8	.2	.6
October 11	1630	2.17	190	7.0	2.5	4.5
October 17	0930	1.76	117	4.0	1.4	2.6
October 24	1035	1.88	137	1.0	0	1.0
1961:						
August 30		2.47	258	6.9	3.2	3.7
1962:						
September 10		1.63	95	1.7	0	1.7
September 10	1240	1.60	91	3.2	.8	2.4
September 12	1500	—	—	2.8	.2	2.6
September 12	1505	—	—	1.2	0	1.2
September 12	1810	—	—	4.6	4.0	.6
September 16	1045	—	—	10.0	8.2	1.8
September 23	1830	—	—	38.6	33.2	5.4
October 19		3.15	435	7.9	6.3	1.6

See footnote at end of table.

Table 6—*Water level, discharge, and suspended sediment measurements: Maybeso Creek, Prince of Wales Island, Alaska, 1957-63* —Continued

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	P.p.m.		
1963:						
September 24	1015	4.50	940	46.6	34.7	11.9
October 10	1530	2.77	332	4.6	1.2	3.4
October 12	1000	2.62	292	3.6	2.5	1.1
October 12	1400	3.10	493	5.5	2.8	2.7
October 12	1535	—	—	5.1	2.6	2.5
October 12	1705	2.54	274	1.9	.6	1.3
October 14		4.35	880	11.0	2.6	8.4
October 19	1440	3.35	510	7.4	5.9	1.5
October 27	1445	2.74	323	2.0	1.9	.1
October 28	1130	2.39	240	1.6	.5	1.1

[1] Specific dates not available for 1957 and part of 1959.

Table 7—*Water level, discharge, and suspended sediment measursements: Indian Creek, Prince of Wales Island, Alaska, 1955-62*

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	P.p.m.		
1955:[1]						
—		—	—	1.0	0	1.0
—		—	—	1.0	0	1.0
—		—	—	11.00	7.0	4.0
1956:[1]						
—		1.96	142	1.0	0	1.0
		1.70	125	1.0	0	1.0
		1.28	59	1.0	0	1.0
1957:[1]						
		.90	20	5.0	0	5.0
		.98	27	3.0	—	—
—		1.06	35	4.0	0	4.0
		1.82	146	3.0	0	3.0
		1.00	29	3.0	—	—
		.72	9	2.0	—	—
November 3		.90	20	3.6	—	—
December 29		.50	3	1.4	—	1.4
1958:						
January 8		1.10	39	.7	—	—
February 24		1.20	50	.7	—	—
May 14		2.86	420	2.5	0	2.5
June 12		.54	4	0	0	0
July 22		.94	24	1.2	—	—
July 31		1.45	84	0	0	0
August 7		1.61	110	0	0	0
August 13		1.00	29	.8	—	—
August 20		1.88	156	0	0	0
August 20		1.95	170	1.7	0	1.7
September 17		1.16	46	0	0	0

See footnote at end of table.

Table 7—*Water level, discharge, and suspended sediment measurements; Indian Creek, Prince of Wales Island, Alaska, 1955-62* —Continued

Date	Time	Water level	Discharge	Suspended sediment		
				Total	Inorganic	Organic
		Feet	C.f.s.	— — — — P.p.m — — — —		
1959:						
June 8		1.22	52	3.5	—	—
June 8		1.12	41	.6	—	—
June 29		.72	9	0	0	0
July 14		2.18	216	1.9	.3	1.6
July 20		1.23	54	1.4	—	—
July 29		.96	25	1.9	—	—
August 20		.90	20	3.5	—	—
September 11		2.64	332	5.3	1.5	3.8
September 18		.96	25	2.7	—	—
September 24		1.30	62	2.4	—	—
December 4		3.00	490	2.6	.2	2.4
1960:						
July 1	1345	.98	27	0	0	0
July 11	1100	1.00	29	.7	.4	.3
July 12	1220	1.52	95	3.2	.9	2.3
July 18	1430	1.08	37	2.7	1.8	.9
July 25		.94	24	.9	0	.9
August 1		.74	10	4.0	0	4.0
August 8	1230	.65	6	5.6	2.6	3.0
August 15		2.20	220	4.1	1.5	2.6
August 22		.93	23	.8	0	.8
August 29	1100	1.16	57	2.4	.9	1.5
September 6	1025	1.43	81	5.2	.8	4.4
September 12	1610	.91	21	3.4	1.7	1.7
September 19	0940	1.29	61	3.5	.2	3.3
September 22	0800	1.77	137	2.3	0	2.3
September 22	1030	1.65	116	2.7	.2	2.5
September 23		1.67	120	.6	.1	.5
September 26	1015	1.18	48	2.1	.9	1.2
October 3		1.35	69	.8	.2	.6
October 5		2.99	485	6.3	1.4	4.9
October 10		3.30	690	10.0	3.6	6.4
October 10	1025	3.46	802	12.5	5.8	6.7
October 17	1100	1.27	58	6.8	3.8	3.0
October 24	1000	1.31	63	3.1	1.3	1.8
1961:						
August 28	0900	2.08	215	6.4	4.9	1.5
August 30		1.93	175	2.0	.6	1.4
September 7		6.60	6,460	57.6	20.0	37.6
September 17	1300	2.50	350	7.4	4.8	2.6
October 1		2.26	265	1.7	.2	1.5
October 2		4.67	1,800	42.8	20.0	22.8
October 3	1015	2.76	450	7.1	2.0	5.1
1962:						
September 12		1.67	120	5.3	1.4	3.9
October 6	1300	2.20	220	3.8	.9	2.9

[1] Specific dates for 1955 to November 3, 1957, not available.

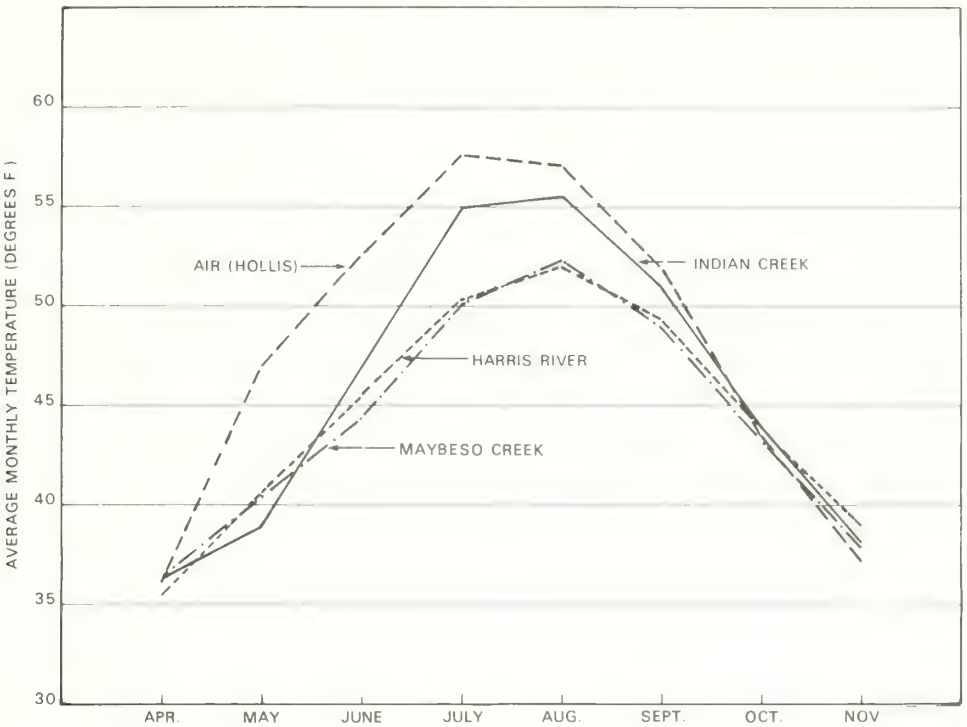

Figure 12 — *Average monthly air and stream temperatures in the study area, Prince of Wales Island, Alaska, 1953-56.*

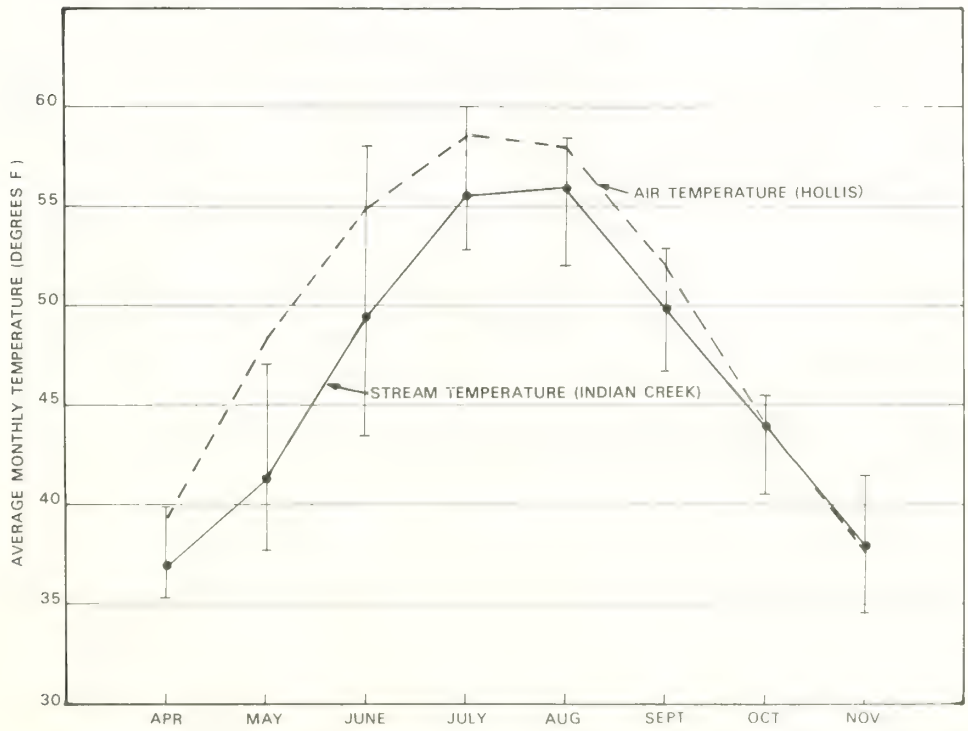

Figure 13 — *Average monthly air temperature at Hollis (dashed line) and stream temperature of Indian Creek (solid line), Prince of Wales Island, Alaska, 1953-62. Vertical lines denote range of average monthly stream temperature over the 10-year period.*

Table 8—*Maximum, average, and minimum monthly temperatures (degrees F.) of Maybeso Creek, Prince of Wales Island, Alaska, 1950-62*[1]

Month	Before logging			During logging					After logging				
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
April:													
Maximum	—	—	—	—	41.0	41.0	40.0	43.0	47.0	—	42.0	—	41.0
Average	—	—	—	—	36.5	36.6	36.2	37.5	40.6	—	37.6	—	37.5
Minimum	—	—	—	—	34.0	33.0	34.0	33.0	37.0	—	35.0	—	35.0
May:													
Maximum	43.0	47.0	—	46.0	44.0	44.0	43.0	51.0	54.0	47.0	45.0	—	49.0
Average	37.8	38.4	—	41.4	40.7	40.2	39.1	42.8	45.3	43.0	39.5	—	43.4
Minimum	34.0	32.0	—	39.0	37.0	37.0	37.0	39.0	41.0	38.0	37.0	—	39.0
June:													
Maximum	54.0	54.0	—	52.0	47.0	46.0	47.0	54.0	65.0	56.0	55.0	—	57.0
Average	44.3	44.5	—	46.1	45.2	43.0	42.8	48.6	58.1	46.8	46.0	—	46.7
Minimum	35.0	38.0	—	42.0	43.0	40.0	40.0	45.0	52.0	42.0	40.0	—	43.0
July:													
Maximum	55.0	64.0	—	57.0	52.0	54.0	59.0	62.0	69.0	57.0	65.0	—	62.0
Average	48.9	54.4	—	52.4	48.2	49.2	50.8	53.2	62.3	53.0	52.9	—	52.8
Minimum	44.0	48.0	—	47.0	45.0	44.0	44.0	48.0	57.0	49.0	48.0	—	47.0
August:													
Maximum	54.0	60.0	—	58.0	56.0	54.0	57.0	64.0	60.0	60.0	67.0	66.0	—
Average	48.6	54.0	—	53.3	53.4	50.2	52.3	56.9	56.4	54.3	55.1	58.1	—
Minimum	43.0	49.0	—	51.0	51.0	49.0	50.0	52.0	52.0	51.0	47.0	53.0	—
September:													
Maximum	53.0	56.0	51.0	53.0	55.0	49.0	54.0	60.0	55.0	52.0	55.0	58.0	—
Average	48.0	49.3	49.8	49.7	50.4	47.6	48.3	53.3	48.9	50.1	49.6	52.2	—
Minimum	39.0	38.0	48.0	46.0	45.0	45.0	43.0	49.0	44.0	48.0	47.0	45.0	—
October:													
Maximum	45.0	—	50.0	48.0	45.0	47.0	45.0	53.0	47.0	50.0	48.0	52.0	—
Average	42.3	—	46.9	45.6	42.9	43.6	41.3	44.8	43.3	46.0	45.1	46.4	—
Minimum	38.0	—	44.0	43.0	39.0	41.0	36.0	41.0	40.0	43.0	42.0	43.0	—
November:													
Maximum	—	—	45.0	43.0	—	42.0	38.0	45.0	44.0	—	44.0	42.0	—
Average	—	—	41.6	40.9	—	36.0	36.6	40.6	39.0	—	40.3	40.0	—
Minimum	—	—	39.0	38.0	—	34.0	36.0	38.0	36.0	—	37.0	35.0	—

[1] Maximum and minimum temperatures recorded to nearest degree.

Table 9 — *Maximum, average, and minimum monthly temperatures (degrees F.) of Harris River, Prince of Wales Island, Alaska,1953-62*[1]

Month	Before logging						During logging			After logging,
	1953[2]	1954	1955	1956	1957	1958	1959	1960	1961	1962
April:										
Maximum	—	40.0	—	40.0	41.0	48.0	43.0	46.0	49.0	46.0
Average	—	35.8	—	35.4	36.8	40.2	39.1	40.2	41.4	40.7
Minimum	—	33.0	—	33.0	33.0	37.0	35.0	36.0	37.0	38.0
May:										
Maximum	48.0	45.0	46.0	46.0	51.0	57.0	48.0	52.0	54.0	52.0
Average	42.8	40.0	40.3	39.6	42.5	45.5	42.8	45.0	47.5	46.1
Minimum	40.0	36.0	37.0	35.0	38.0	40.0	39.0	42.0	42.0	40.0
June:										
Maximum	57.0	49.0	49.0	50.0	54.0	67.0	56.0	—	59.0	58.0
Average	48.2	45.4	43.4	45.0	48.3	57.1	47.4	—	51.3	48.5
Minimum	42.0	42.0	40.0	41.0	45.0	51.0	43.0	—	48.0	44.0
July:										
Maximum	62.0	54.0	55.0	62.0	63.0	67.0	59.0	—	67.0	67.0
Average	57.8	49.6	48.2	53.0	51.8	60.5	51.6	—	56.6	56.4
Minimum	47.0	46.0	43.0	46.0	47.0	50.0	47.0	—	51.0	48.0
August:										
Maximum	—	49.0	51.0	59.0	62.0	57.0	57.0	—	67.0	—
Average	—	55.0	48.7	52.3	56.1	53.7	52.4	—	58.2	—
Minimum	—	51.0	47.0	49.0	52.0	50.0	49.0	—	53.0	—
September:										
Maximum	53.0	58.0	50.0	53.0	54.0	57.0	52.0	55.0	57.0	—
Average	50.0	51.1	47.3	49.2	49.9	49.7	50.2	50.6	51.5	—
Minimum	46.0	45.0	43.0	43.0	45.0	46.0	48.0	48.0	45.0	—
October:										
Maximum	48.0	47.0	47.0	46.0	50.0	50.0	51.0	50.0	52.0	—
Average	46.4	43.5	42.9	41.9	42.8	45.0	46.1	47.9	46.1	—
Minimum	43.0	39.0	40.0	36.0	38.0	41.0	40.0	45.0	41.0	—
November:										
Maximum	44.0	44.0	41.0	39.0	44.0	46.0	45.0	45.0	41.0	—
Average	41.6	42.5	34.4	37.5	42.0	38.7	39.1	40.9	38.0	—
Minimum	39.0	39.0	32.0	35.0	39.0	35.0	34.0	36.0	33.0	—

[1] Maximum and minimum temperatures to nearest degree.
[2] First year of record.

Table 10—*Maximum, average, and minimum monthly temperatures (degrees F.) of the unlogged watershed of Indian Creek, Prince of Wales Island, Alaska, 1950-62*[1]

Month	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
April:													
Maximum	—	—	—	—	—	41.0	37.0	39.0	46.0	40.0	39.0	44.0	38.0
Average	—	—	—	—	—	37.0	35.4	35.5	39.8	36.7	36.2	38.8	36.5
Minimum	—	—	—	—	—	35.0	34.0	33.0	36.0	34.0	34.0	36.0	34.0
May:													
Maximum	41.0	48.0	—	—	—	44.0	43.0	54.0	58.0	48.0	44.0	51.0	45.0
Average	34.5	36.5	—	—	—	38.4	37.7	42.2	47.0	41.1	40.3	47.0	40.8
Minimum	30.0	30.0	—	—	—	36.0	36.0	37.0	41.0	37.0	37.0	43.0	37.0
June:													
Maximum	59.0	64.0	—	63.0	52.0	50.0	50.0	58.0	68.0	62.0	54.0	55.0	54.0
Average	44.4	46.8	—	51.0	47.8	43.5	45.2	51.7	58.0	50.8	48.1	51.6	49.0
Minimum	33.0	36.0	—	42.0	45.0	39.0	39.0	46.0	49.0	45.0	42.0	50.0	44.0
July:													
Maximum	62.0	64.0	—	67.0	58.0	63.0	64.0	62.0	67.0	61.0	60.0	63.0	57.0
Average	51.8	55.8	—	57.3	52.8	54.7	54.4	53.6	60.0	54.5	53.3	57.8	54.7
Minimum	45.0	49.0	—	50.0	49.0	48.0	48.0	49.0	54.0	51.0	51.0	52.0	51.0
August:													
Maximum	64.0	62.0	—	63.0	60.0	57.0	61.0	62.0	61.0	58.0	61.0	64.0	—
Average	54.4	52.8	—	57.5	56.6	52.0	54.9	57.0	55.7	53.8	54.6	58.5	—
Minimum	49.0	44.0	—	52.0	52.0	50.0	51.0	51.0	51.0	50.0	48.0	55.0	—
September:													
Maximum	56.0	58.0	54.0	59.0	57.0	54.0	54.0	57.0	56.0	53.0	53.0	54.0	—
Average	49.3	48.2	51.2	51.4	51.4	49.9	49.6	52.8	46.9	50.6	49.9	53.2	—
Minimum	39.0	36.0	49.0	45.0	43.0	45.0	42.0	46.0	42.0	48.0	48.0	48.0	—
October:													
Maximum	46.0	—	51.0	49.0	—	48.0	45.0	52.0	50.0	51.0	49.0	52.0	—
Average	42.4	—	46.9	45.6	—	42.8	40.6	43.7	44.9	44.8	45.5	45.0	—
Minimum	38.0	—	44.0	42.0	—	38.0	34.0	38.0	39.0	39.0	41.0	39.0	—
November:													
Maximum	—	—	45.0	—	—	40.0	38.0	45.0	46.0	44.0	45.0	40.0	—
Average	—	—	39.7	—	—	34.7	36.5	41.7	38.6	36.0	39.6	36.3	—
Minimum	—	—	34.0	—	—	34.0	34.0	38.0	35.0	32.0	36.0	34.0	—

[1] Maximum and minimum temperatures recorded to nearest degree.

Table 11 *Average stream temperature differences (degrees F.), Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1950-62.*

MONTH	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
Maybeso Creek minus Indian Creek:													
April	—	—	—	—	—	-0.4	0.8	2.0	0.8	—	1.4	—	1.0
May	3.3	1.9	—	—	—	1.8	2.4	.6	-1.7	1.9	-.8	—	2.6
June	-.1	-2.3	—	-4.9	-2.6	-.5	-2.4	-3.1	.1	-4.0	-2.1	—	-2.3
July	-2.9	-1.4	—	-4.9	-4.6	-5.5	-3.6	-.4	2.3	-1.5	-.4	—	-1.9
August	-5.8	1.2	—	-4.2	-3.2	-1.8	-2.6	-.1	.7	.5	.5	-0.4	—
Sept.	-1.3	1.1	-1.4	-1.7	-1.0	-2.3	-1.3	.5	2.0	-.5	-.3	-1.0	—
Oct.	-.1	—	0	0	—	.8	.7	1.1	-1.6	1.2	-.4	1.4	—
Nov.	—	—	1.9	—	—	1.3	.1	-1.1	.4	—	.7	3.7	—
Maybeso Creek minus Harris River:													
April	—	—	—	—	.7	—	.8	.7	.4	—	-2.6	—	-3.2
May	—	—	—	-1.4	.7	-.1	-.5	.3	-.2	.2	-5.5	—	-2.7
June	—	—	—	-2.1	-.2	-.4	-2.2	.3	1.0	-.6	—	—	-1.8
July	—	—	—	-5.4	-1.4	1.0	-2.2	1.4	1.8	1.4	—	—	-3.6
August	—	—	—	—	-1.6	1.5	0	.8	2.7	1.9	—	-.1	—
Sept.	—	—	—	-.3	-.7	.3	-.9	3.4	-.8	-.1	-1.0	.7	—
Oct.	—	—	—	-.8	-.6	7	-.6	2.0	-1.7	-.1	-2.8	.3	—
Nov.	—	—	—	-.7	—	1.6	-.9	-1.4	.3	—	-.6	2.0	—
Harris River minus Indian Creek:													
April	—	—	—	—	—	—	0	1.3	.4	2.4	4.0	2.6	4.2
May	—	—	—	—	—	1.9	1.9	.3	-1.5	1.7	4.7	.5	5.3
June	—	—	—	-2.8	-2.4	-.1	-.2	-3.4	-.9	-3.4	—	-.3	-.5
July	—	—	—	.5	-3.2	-6.5	-1.4	-1.8	.5	-2.9	—	-1.2	-1.7
August	—	—	—	—	-1.6	-3.3	-2.6	-.9	-2.0	-1.4	—	-.3	—
Sept.	—	—	—	-1.4	-.3	-2.6	-.4	-2.9	2.8	-.4	.7	-1.7	—
Oct.	—	—	—	.8	—	.1	1.3	-.9	.1	1.3	2.4	1.1	—
Nov.	—	—	—	—	—	-.3	1.0	.3	.1	3.1	1.3	1.7	—

Table 12—*Occurrence of stream temperaturesof 60° F. or more in Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66.*

Stream and year	Maximum stream temperature	Total time	Maximum duration	Days
	Degrees F	Hours	Hours	Number
Maybeso Creek:				
1953	< 60	0	0	0
1954	< 60	0	0	0
1955	< 60	0	0	0
1956	< 60	0	0	0
1957	64	123	11	18
1958	69	765	187	35
1959	60	4	4	1
1960	67	128	15	13
1961[1]	66	167	44	14
1962	62	14	7	2
1963	64	198	14	25
1964	< 60	0	0	0
1965	65	367	150	28
1966	68	162	17	18
Harris River:				
1953	62	27	7	5
1954	< 60	0	0	0
1955	< 60	0	0	0
1956	62	23	6	6
1957	63	63	7	12
1958[1]	67	190	37	21
1959	< 60	0	0	0
1960[2]	—	—	—	—
1961[1]	67	322	34	29
1962	67	244	64	18
1963	65	608	134	35
1964[1]	< 60	0	0	0
1965	64	264	91	24
1966	65	155	19	17
Indian Creek:				
1953	67	312	44	27
1954	60	14	8	2
1955	63	32	12	6
1956	64	69	12	11
1957	62	95	11	13
1958	68	594	39	48
1959	64	36	7	5
1960	61	43	11	5
1961	64	447	231	30
1962	< 60	0	0	0
1963[2]	—	—	—	—
1964[2]	—	—	—	—
1965[2]	—	—	—	—
1966	65	127	16	13

[1] Instrument was not recording part of season.
[2] No data.

Table 13—*Total number of days when stream temperature was from 60° to 70° F. in Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	60	61	62	63	64	65	66	67	68	69	70
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	18	12	11	6	3	0	0	0	0	0	0
1958	35	37	32	30	27	22	19	15	11	3	0
1959	1	0	0	0	0	0	0	0	0	0	0
1960	13	8	7	6	6	5	1	1	0	0	0
1961[1]	14	12	12	10	6	3	3	0	0	0	0
1962	2	2	1	0	0	0	0	0	0	0	0
1963	25	19	11	5	2	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	28	21	19	18	13	10	1	0	0	0	0
1966	18	14	10	9	6	3	3	3	2	0	0
Harris River:											
1953	5	3	1	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	6	2	1	0	0	0	0	0	0	—	—
1957	12	6	3	1	0	0	0	0	0	—	—
1958[1]	21	13	11	8	8	4	2	1	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	29	25	20	14	9	4	2	1	0	—	—
1962	18	14	11	10	8	6	5	4	0	—	—
1963	35	26	22	14	4	1	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	24	15	14	8	3	0	0	0	0	—	—
1966	17	12	9	7	5	2	0	0	0	—	—
Indian Creek:											
1953	27	16	10	9	5	3	2	1	0	0	—
1954	2	0	0	0	0	0	0	0	0	0	—
1955	6	3	2	1	0	0	0	0	0	0	—
1956	11	4	3	2	1	0	0	0	0	0	—
1957	13	7	3	0	0	0	0	0	0	0	—
1958	48	38	29	24	22	13	13	7	1	0	—
1959	5	4	3	0	0	0	0	0	0	0	—
1960	5	1	0	0	0	0	0	0	0	0	—
1961	30	20	12	8	3	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	13	10	7	5	3	2	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Table 14—*Total number of hours when stream temperature was 60° to 70° F., in Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	60	61	62	63	64	65	66	67	68	69	70
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	48	22	28	14	12	0	0	0	0	0	0
1958	174	142	115	77	68	50	42	32	47	18	0
1959	4	0	0	0	0	0	0	0	0	0	0
1960	39	14	11	9	14	18	2	3	0	0	0
1961[1]	47	27	35	23	18	5	12	0	0	0	0
1962	4	7	3	0	0	0	0	0	0	0	0
1963	77	57	40	15	9	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	121	96	43	28	33	42	4	0	0	0	0
1966	47	32	19	24	14	5	7	9	5	0	0
Harris River:											
1953	14	11	2	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	16	6	1	0	0	0	0	0	0	—	—
1957	38	17	6	2	0	0	0	0	0	—	—
1958[1]	76	38	26	17	20	7	4	2	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	112	65	57	43	24	12	5	4	0	—	—
1962	64	54	29	28	21	18	15	15	0	—	—
1963	359	88	77	60	21	3	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	162	29	40	23	10	0	0	0	0	—	—
1966	53	36	22	20	16	8	0	0	0	—	—
Indian Creek:											
1953	119	86	44	33	13	13	2	2	0	0	—
1954	14	0	0	0	0	0	0	0	0	0	—
1955	12	7	10	3	0	0	0	0	0	0	—
1956	46	5	11	3	4	0	0	0	0	0	—
1957	49	37	9	0	0	0	0	0	0	0	—
1958	212	114	88	60	56	22	25	15	2	0	—
1959	14	12	10	0	0	0	0	0	0	0	—
1960	37	6	0	0	0	0	0	0	0	0	—
1961	186	127	71	40	23	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	37	33	22	17	12	6	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Table 15—*Number of consecutive hours when stream temperature was greater than 59° to 69° F., Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	>59	>60	>61	>62	>63	>64	>65	>66	>67	>68	>69
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	11	9	8	6	5	0	0	0	0	0	0
1958	187	156	58	19	16	14	12	10	9	6	0
1959	4	0	0	0	0	0	0	0	0	0	0
1960	15	12	10	9	7	6	5	3	0	0	0
1961[1]	44	16	12	9	8	7	4	0	0	0	0
1962	7	6	3	0	0	0	0	0	0	0	0
1963	14	11	9	7	5	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	150	37	15	12	9	6	0	0	0	0	0
1966	17	16	12	11	10	9	7	5	3	0	0
Harris River:											
1953	7	6	2	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	6	5	1	0	0	0	0	0	0	—	—
1957	7	5	4	2	0	0	0	0	0	—	—
1958[1]	37	14	11	9	7	4	3	2	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	34	17	13	11	9	8	6	4	0	—	—
1962	64	37	19	15	12	10	8	5	0	—	—
1963	134	18	14	9	7	3	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	91	15	10	8	6	0	0	0	0	—	—
1966	19	15	13	9	7	4	0	0	0	—	—
Indian Creek:											
1953	44	38	34	16	12	8	3	2	0	0	—
1954	8	0	0	0	0	0	0	0	0	0	—
1955	12	9	7	3	0	0	0	0	0	0	—
1956	12	10	8	7	4	0	0	0	0	0	—
1957	11	8	5	0	0	0	0	0	0	0	—
1958	39	36	16	12	10	8	4	3	2	0	—
1959	7	6	4	0	0	0	0	0	0	0	—
1960	11	6	0	0	0	0	0	0	0	0	—
1961	231	42	17	12	10	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	16	13	12	9	8	3	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Table 16—*Greatest number of consecutive hours when stream temperature was 60° to 70° F., Maybeso Creek, Harris River, and Indian Creek, Prince of Wales Island, Alaska, 1953-66*

Stream and year	Stream temperature (degrees F.)										
	60	61	62	63	64	65	66	67	68	69	70
Maybeso Creek:											
1953	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	0	0	0	0
1956	0	0	0	0	0	0	0	0	0	0	0
1957	5	3	5	4	5	0	0	0	0	0	0
1958	27	11	18	5	7	6	5	5	7	6	0
1959	4	0	0	0	0	0	0	0	0	0	0
1960	6	2	3	1	5	5	1	3	0	0	0
1961[1]	10	3	7	6	6	1	4	0	0	0	0
1962	1	4	3	0	0	0	0	0	0	0	0
1963	8	6	7	5	5	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0
1965	11	20	6	7	6	6	0	0	0	0	0
1966	4	5	3	7	4	1	2	2	3	0	0
Harris River:											
1953	4	6	2	0	0	0	0	0	0	—	—
1954	0	0	0	0	0	0	0	0	0	—	—
1955	0	0	0	0	0	0	0	0	0	—	—
1956	4	3	1	0	0	0	0	0	0	—	—
1957	7	4	2	2	0	0	0	0	0	—	—
1958[1]	10	11	6	2	6	2	2	2	0	—	—
1959	0	0	0	0	0	0	0	0	0	—	—
1960[2]	—	—	—	—	—	—	—	—	—	—	—
1961[1]	17	11	8	5	5	4	4	4	0	—	—
1962	5	17	5	6	5	5	4	5	0	—	—
1963	50	10	10	8	6	3	0	0	0	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965	34	5	6	7	6	0	0	0	0	—	—
1966	0	6	3	4	5	4	0	0	0	—	—
Indian Creek:											
1953	12	14	17	6	4	5	1	2	0	0	—
1954	8	0	0	0	0	0	0	0	0	0	—
1955	5	3	6	3	0	0	0	0	0	0	—
1956	7	2	6	5	4	0	0	0	0	0	—
1957	7	8	5	0	0	0	0	0	0	0	—
1958	22	8	9	5	8	4	3	3	2	0	—
1959	7	6	4	0	0	0	0	0	0	0	—
1960	11	6	0	0	0	0	0	0	0	0	—
1961	31	21	13	11	10	0	0	0	0	0	—
1962	0	0	0	0	0	0	0	0	0	0	—
1963[2]	—	—	—	—	—	—	—	—	—	—	—
1964[2]	—	—	—	—	—	—	—	—	—	—	—
1965[2]	—	—	—	—	—	—	—	—	—	—	—
1966	5	7	5	7	4	3	0	0	0	0	—

[1] Instrument not recording part of season.
[2] No data.

Maybeso Creek. — Clearcutting began on the Maybeso Creek watershed in 1953 and ended in 1957. Stream temperature changes were not apparent when areas to the northeast of the creek were clearcut between 1953 and 1956, but during the summer of 1957, increases were detectable after two blocks were clearcut on the southwest side of the creek near the gaging site. Normal variations in sream temperature probably masked small changes during the other months.

Analysis of covariance was used to test for logging effect on average monthly stream temperature. In conduction of the analysis, each month (April through November) was considered separately. A combined linear model was not used because average monthly stream temperatures for any given year are serially correlated. It was also evident that the relationship between temperature of Indian Creek, the control stream, and those of Maybeso Creek and Harris River, was a function of time of year (fig. 12). A month-by-month comparison eliminated both problems.

For the analysis of covariance by month, the temperature of Indian Creek was used as a covariate in one series of tests and the temperature of Harris River as a covariate in a second series (table 17). July and August showed significant (at the 5-percent level) stream temperature increases due to logging. November also showed a significant stream temperature increase due to logging when the temperature of Indian Creek was used as a covariate. Other monthly increases were nonsignificant or there was insufficient data to test the hypothesis that logging did not affect stream temperature. From this analysis it appears that, at the gaging site, the maximum increase in average monthly stream temperature was about 4° F.

A comparison of maximum observed stream temperatures (tables 8-10 and 12-16) also indicates that significant changes in maximum stream temperature occurred only during the months of July and August. The increase in maximum temperatures was about 9° F.

Table 17—*Increase in average stream temperatures due to logging; Maybeso Creek (1953-57) and Harris River (1959-61), Prince of Wales Island, Alaska*

Month	Temperature increase		
	Maybeso Creek, with Indian Creek as a control	Maybeso Creek, with Harris River as a control	Harris River, with Indian Creek as a control
	Degrees F		
April	0.67	0.06	2.64*
May	.74	1.36	3.33*
June	.35	1.16	1.45
July	3.12*	4.24*	1.97
August	3.50*	2.77*	(1)
September	.95	1.36	1.18
October	.05	.50	1.37
November	3.10*	1.97[1]	1.22

*Significant at the 5-percent level.
[1] Insufficent data for a good test.

Winter temperatures, taken at the Maybeso Creek gaging site, showed no detectable change after clearcutting. After ice formed on the stream, temperatures remained between 32° and 34° F. until spring.

Harris River. — Clearcutting operations began in the Harris River watershed in the summer of 1959. By the spring of 1960, there was an indication that logging was affecting stream temperature (table 11). Unfortunately, however, detailed stream temperature comparisons during and after clearcutting were not possible, as much of the 1960-62 data for Harris River and the other streams are incomplete. An analysis of covariance was run on the available data using the temperature of Indian Creek as a covariate. Results of the analysis (table 17) showed an average increase for all months from April through November of from 1° to 3.5° F. However, only the months of April and May showed a significant change in average monthly stream temperature. Possibly if more data had been available, other months would also have shown significant increases.

It is evident from comparison of the maximum stream temperatures of Harris River and Indian Creek (tables 9-10 and 12-16) that maximum stream temperatures rose from 4° to 9° F. for the months April through September as a result of logging. October and November show no noticeable increase in maximum stream temperatures. Logging also caused an increase in the range of monthly temperatures.

Even though we could not prove it statistically, there is considerable evidence to indicate that, for the months of April through November, the temperature of Harris River was affected by logging the watershed. Average monthly stream temperature rose from 1° to 3.5° F., and the range between maximum and minimum temperatures increased.

Available winter temperatures from the Harris River gaging site suggest that clearcutting had little, if any, effect on winter temperatures. As in the case of Maybeso Creek, after Harris River froze over, stream temperatures at the gaging site remained between 32° and 34° F. until spring.

LOG-DEBRIS JAMS

Debris obstructions in the study streams were not observed to impede salmon migration. Numbers of wood pieces large enough to jam the study streams are tabulated below, indicating more logging debris in Maybeso Creek than in Harris River.

	Maybeso Creek	Harris River	Indian Creek
Before clearcutting	1,120	224	410
During clearcutting	1,819	282	442
After clearcutting	1,603	284	402

Equal lengths of streambank (3.4 miles) were clearcut along Maybeso Creek and Harris River, although more than 5 miles were mapped to show log-debris jams. Only 3.6 miles of streambank were mapped along Indian Creek.

SALMON POPULATIONS

Escapement surveys (U.S. Fish and Wildlife Service 1963) were made by different observers using different counting methods and aircraft under various conditions of light, weather, and availability of time, funds, and personnel (fig. 14, table 18). These estimates are useful for fishery regulation but are unreliable as measures of logging effects on salmon populations; they indicate increases in salmon production following logging, the probable reasons for which are discussed later.

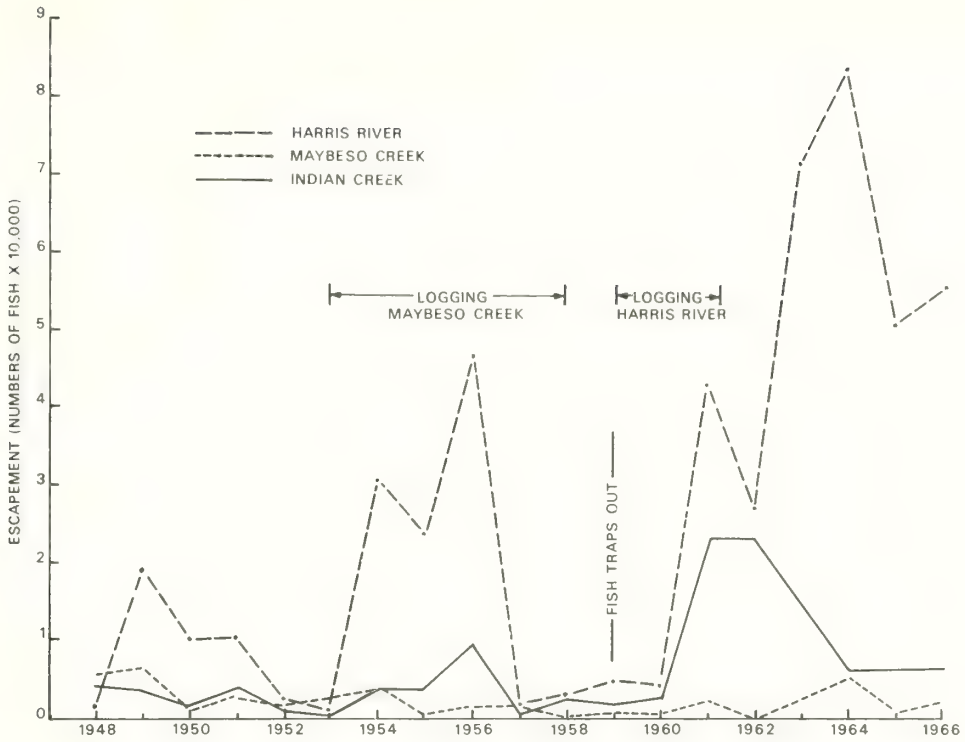

Figure 14 — *Estimated numbers of pink and chum salmon spawning in Hollis area streams, Prince of Wales Island, Alaska, 1948-66.*

Estimates of live pink salmon alevins (preemergent fry) per square meter in the intertidal area of Harris River (Sheridan and McNeil 1968) were:

Year	Alevins per square meter (Number)
1958	12
1959	107
1960	123
1961	71
1962	82
1963	168
1964	116
1965	203

These data, based on annual samples dug from the spawning beds, are a more reliable index of salmon production than spawner counts. Unfortunately, this technique[9] was not developed until 1958, so comparable alevin counts are unavailable for the prelogging period. However, Sheridan and McNeil's data (1968) may be compared with the following standards established by the Alaska Department of Fish and Game (Hoffman 1966):[10]

Good production more than 250 alevins per square meter.

Fair production, 100-250 alevins per square meter.

Poor production, less than 100 alevins per square meter.

[9] McNeil, William J. Mortality of pink and chum salmon and chum salmon eggs and larvae in southeast Alaska streams. 271 pp., 1962. (Ph.D. thesis on file School of Fish., Univ. Wash.)

[10] These are preliminary values subject to change.

Table 18—*Escapements of spawning pink and chum salmon into study streams, Prince of Wales Island, 1948-66*

Year	Maybeso Creek			Harris River			Indian Creek		
	Pink	Chum	Total	Pink	Chum	Total	Pink	Chum	Total
1948	100	5,200	5,300	10,000	4,000	14,000	3,700	100	3,800
1949	5,500	900	6,400	17,300	1,600	18,900	3,500	100	3,600
1950	300	500	800	8,600	1,600	10,200	1,400	0	1,400
1951	700	2,000	2,700	6,200	4,300	10,500	3,600	500	4,100
1952	100	1,400	1,500	2,100	300	2,400	800	0	800
1953	0	2,000	2,000	600	300	900	300	0	300
1954	2,700	1,300	4,000	30,000	600	30,600	4,000	0	4,000
1955	100	300	400	22,000	1,700	23,700	3,500	0	3,500
1956	400	800	1,200	45,000	1,800	46,800	9,000	100	9,100
1957	0	1,100	1,100	1,500	300	1,800	500	0	500
1958	0	0	0	2,800	200	3,000	2,100	0	2,100
1959	100	0	100	4,700	0	4,700	1,500	0	1,500
1960	0	400	400	4,600	0	4,600	2,400	0	2,400
1961	0	2,400	2,400	—	—	43,000	23,000	0	23,000
1962	0	0	0	—	—	27,000	23,000	0	23,000
1963	2,500	0	2,500	63,000	8,300	71,300	(1)	(1)	(1)
1964	1,000	4,000	5,000	82,000	1,500	83,500	6,000	0	6,000
1965	800	100	900	—	—	50,400	—	—	—
1966	—	—	2,100	—	—	55,000	6,100	0	6,100

[1] Not surveyed after August 15.

DISCUSSION

Our results will be discussed within the framework of the study objective; i.e., the effects of clearcutting on various aspects of salmon habitat. For better presentation of this material, some interpretations of the effects of clearcutting on streamflow will be incorporated in the discussion.

STREAMFLOW

Quantity

Changes in water yield were not detectable by the methods used, but the effect of clearcutting on water yield can be deduced from other studies. In its simplest form, the streamflow equation (streamflow = precipitation — evaporative loss) shows how. Clearcutting more than 20 percent of forests in humid regions usually reduces evaporative losses and increases streamflow (Douglass 1966). Initial increases tend to be largest, then streamflow decreases as forest vegetation regrows (Hewlett and Hibbert 1961). A practical upper limit of initial streamflow increase appears to be about 4.5 mm. (0.18 inch) per year for each percent reduction in forest cover (Hibbert 1967). Since 20 percent of Harris River and 25 percent of Maybeso Creek watersheds were clearcut, a maximum increase of about 4½ inches of streamflow

is all that could be expected. Lesser increases must have occurred because the clearcutting took several years to complete and streamflow probably declined as trees and other vegetation regrew on earlier cuttings. A somewhat different approach provides a similar estimate of streamflow increase. If clearcutting prevented all evaporative loss, then the maximum streamflow increase possible would be about 25 percent (fraction of watersheds clearcut) multiplied by 21.41 (potential evapotranspiration at Hollis), or 5.4 inches. Since evaporative loss was decreased by clearcutting but never prevented, a streamflow increase of 3 to 4 inches seems realistic. Detection of this increase by streamflow measurements would require rain-gage networks and weirs capable of estimating precipitation and streamflows to accuracy of $\pm$ 2 to 3 percent. Since our measurements lacked this prohibitively expensive degree of accuracy, streamflow increases following clearcutting could not be demonstrated.

Because increased annual flow following clearcutting is consistent with world experience (Hibbert 1967), it is relevant to speculate as to when during the year augmented flows would have appeared. Hibbert's review suggests that occurrence of increased streamflow depends on kind of precipitation. Streamflow increases in springtime usually result from snowmelt, whereas streamflow increases during the growing season usually result from rainfall. The study watersheds, being amply supplied with both rain and snow, probably had augmented flows whenever air temperatures rose above freezing. This reasoning also suggests augmented low flows during both summer and winter.

Regimen

Clearcutting evidently had little effect on regimen of the study streams. It is unlikely that logging influenced the water-conducting capabilities of deep soil or bedrock. The scant evidence available suggests that logging in other regions decreased the infiltration rate by compaction; i.e., decreased macroscopic pore space of surface soils. We closely examined the literature for evidence of how clearcutting might influence infiltration.

"Infiltration is the first modifier in the land phases of the hydrologic cycle. It is the major factor determining the disposition of water falling as rain and, further, it is a highly manageable process; yet, it is most frequently circumvented in hydrologic computations" (Holtan et al. 1967).

There is no doubt that vehicle traffic, falling trees, dragging logs, and human foot travel compacted soil on clearcut land. Questions of how deeply the soil was compacted, how infiltration rates were influenced, and how long impairment of hydrologic functions persisted cannot be answered to complete satisfaction. Lull's (1959) review suggests that compaction may be temporary in forest soils of other regions. He states that "under wetter conditions, imbibition and swelling of fine-textured soils reduces density. Freezing and thawing (with the concomitant 9-percent change in volume of moisture) would also be a factor in loosening compacted soils." Patric (1967) reported frost penetration to 18 inches on a clearcutting near Juneau. Although there is probably less soil freezing at Hollis due to the warmer climate, there is ample frost action to break up minor forest soil compaction. Lull (1959) cites another experiment in which buried cores of puddled soil showed structural restoration within a year in the presence of high organic content and exposure to moisture and temperature variation. The rapid revegetation of Maybeso valley reported by Harris (1967) also would tend to reduce soil compaction by root penetration. The pedologic characteristics, described by Gass et al. (1967) and summarized on page 5 and in figure 5, make timbered soils resistant to damage by clearcutting. Infiltration remains high after clearcut logging because the deep organic layer is not usually scoured away to mineral soil. Water moves very rapidly through the mineral soil, which also has high resistance to erosion. Patric and Swanston (1968) irrigated reforested plots

in Maybeso valley at the rate of 0.7 inch per hour for periods ranging from 18 hours to 1 month. Over 400 inches of water were applied to one plot; minor surface runoff occurred only when a broken pipe caused 6 inches of water per hour to fall on a small area. Since the estimated 100-year maximum rainfall rate for the region is only 1.4 inches per hour (Miller 1963), we concluded that surface runoff rarely, if ever, occurred on the clearcut areas of the watershed.

WATER QUALITY

Suspended Sediment

Suspended sediment samples from the study streams are our best evidence that clearcutting had little or no effect on water quality. Materially reduced infiltration rates would have started the familiar sequence of surface runoff and sediment laden streams. Had stormflows increased even slightly, soils and organic matter scoured from streambanks also would have entered the streams. The logging road surfaces show little evidence of erosion but washouts, scouring ditches, and unvegetated cut or fill slopes remain as sediment sources. Most sediment, however, is trapped on the absorbent litter and soil between source areas and streams.

Heavy rains in October 1961 caused a marked increase in debris avalanches (defined by Sharpe 1960) and debris flows (defined by Rapp 1961) on clearcut portions of the Maybeso Creek watershed (Bishop and Stevens 1964). It is estimated that approximately 11 percent of a mile-square clearcut area in Maybeso valley has been affected by these forms of erosion since 1959 (Harris 1967).

Debris avalanches are common on forested Karta soil (Gass et al. 1967) and are a normal part of postglacial adjustment in southeast Alaska.[11] More than a hundred debris avalanches have occurred in Maybeso valley since 1953 when logging began in the area; only one of these actually reached Maybeso Creek. Avalanche material usually came to rest at the base of steep slopes, well removed from the main stream channel.

Debris flows probably contributed sediment to salmon streams, but our data suggests that this contribution was small. Several debris flows occurred on the clearcuttings, where logging slash had formed temporary dams in steep-walled tributary streams. These dams burst during heavy rain and carried sediment to Maybeso Creek and Harris River. The unvegetated scars remain as sediment sources.

We believe that clearcutting and logging increased suspended sediments slightly but that water quality was only briefly reduced.

Stream Temperature

Clearcutting operations in Maybeso Creek and Harris River watersheds apparently did not appreciably alter the factors that control stream temperature at the gaging sites. After analysis of the data, we conclude that winter temperatures were little affected and that average temperature changes at other times of the year were 4° F. or less.

As with most stream temperature data that has been gathered elsewhere in the past, sampling within and between streams was not detailed enough to analyze the total effect of stand treatment on stream temperature. It is possible that the single temperature probe in each stream was located in an area that showed either maximum or minimum temperature change. Maybeso Creek temperatures, for example, showed no change until the timber on the southwest side of the stream near the gaging site was clearcut. Even then, it was not possible to evaluate accurately the increase in temperature, as comparisons with Indian Creek and Harris River temperatures showed year-to-year variation (table 11). This variation may, in part, reflect differences between the watersheds.

[11] See footnote 7.

It is possible that removal of timber along the banks of streams in coastal Alaska is the most significant factor in altering stream temperature. In summer months this allows more solar radiation to reach the stream and in winter the streams are more exposed to colder air temperatures. In winter months, under an ice layer, stream temperature remained in the 32° to 34° F. range. We do not know if removal of streamside timber affects freezing of the streambeds.

LOG-DEBRIS JAMS

The reasons for fewer log-debris jams in Harris River are unknown. The marked increase in debris jams in Maybeso Creek during and after clearcutting may be explained in that the logged portions of Maybeso Creek drainage were more densely forested than those of Harris River. In addition, red alder *(Alnus rubra* Bong.*)*, growing along Maybeso Creek, was poisoned in 1952 to minimize seed sources of this species (Anderson 1953); dead alder fell into the stream and was incorporated into jams.

Aerial photographs taken in 1961 and 1962 indicated that major shifts of debris jams accompanied stormflow peaks during heavy autumn rains (fig. 15). Shifts in pool and riffle structure accompanied these debris shifts. Helmers' (1966) summary of observations showed that debris jams in Maybeso Creek tended to increase streambed movement and decrease sediment levels in streambed gravel. Even small storms sometimes caused major relocations of log jams and stream channels on all the study streams.

BIOLOGICAL EFFECTS

The final effects of man's activities on salmon habitat are best observed by examination of the fish populations themselves.

Figure 15—*During stormflow peaks, major shifts of log-debris jams caused streambed changes. Gravel deposits above or below jams washed downstream when obstructions were carried away, and pools under jams refilled with bedload material.*

Results show that salmon populations in the study streams did not decrease after logging; in fact, they generally increased, particularly in Harris River. However, two concurrent events may have affected salmon production in the Hollis streams: (1) removal of fish traps from nearby waters and (2) clearcutting. The probable increase in escapement resulting from trap removal could have masked any change in production resulting from clearcutting — if a change occurred.

Another way to evaluate the possible effects of clearcutting on salmon production is to consider how changes in streamflow and temperature could influence the fresh water phases of salmon life history. Pink and chum salmon deposit their eggs in streambed gravels late in the summer. The eggs incubate over winter, and fry hatch during late winter and early spring. When the yolk sac is almost fully absorbed, the fry emerge from the gravel and migrate downstream to the sea. After spending 1½ to 4½ years at sea, they return to their natal streams to spawn and die. In general, then, when streamflow is usually low (June-August), pink and chum salmon fry are not in the streams. Adult salmon begin to enter the streams in August, after which spawning takes place.

Our data showed no measurable effect of clearcutting on flow of study streams; however, streamflow must have slightly increased. Increases during the summer months could be beneficial by making spawning grounds more accessible. On the other hand, greatly increased streamflow during spawning could result in egg deposition in gravel beds which would be exposed and frozen during low winter streamflows.

The year-to-year variation in average monthly stream temperatures tended to mask effects of clearcutting on study streams, although the entire range of temperature shifted upward after clearcutting. Warmest stream temperatures occurred between June and mid-August; the maximum temperature recorded in any study stream was 69° F. in Maybeso Creek. Since most of these maximum temperatures occurred when pink and chum salmon generally are absent from the study streams, biologically significant effects on these two species would not be expected.

It appears that clearcutting caused average temperatures in the study streams to increase not more than 1° to 4° F. from April through November. The natural year-to-year variations in average temperatures during these months often are greater than the treatment effect. Therefore, in some years, the incubation and hatching of eggs and fry might be unaffected by clearcutting. During years of exceptionally warm temperatures in September-November, the additional 1°-3° F. treatment effect in these months could accelerate incubation and hatching. If fry hatched somewhat earlier than usual, they might adjust to this situation by remaining somewhat longer in the streambed gravels before emerging. However, if stream temperatures were unusually warm during late summer and early fall, it is conceivable that fry might emerge from the gravel and migrate to sea prior to freezeup, perhaps in December. It would appear that the marine environment at this time of year would not be favorable for good growth and survival of the young salmon.

In streams of high gradient and velocity, occasional stable debris jams could serve to reduce velocity on upstream spawning reaches and cause sediment to be deposited in the immediate vicinity.

In slower streams with less gradient, jams probably are more harmful since they tend to reduce velocity even further and, perhaps, prohibit natural flushing of sediment from spawning gravels. If jams are numerous on a given stream, they could occupy considerable space.

In either case, if a jam blocks passage of anadromous fishes to suitable spawning and rearing areas upstream, it may limit production in that system. Unstable jams may shift or dislodge debris during high

water, thereby scouring gravels from downstream areas. The size composition, structure, and stability of bed material would also be important considerations in evaluating the effects of a jam in a given stream.

In general, then, the results of this study do not indicate any obvious effects of clearcutting on the salmon populations in the two streams considered. Some more subtle changes may have occurred that were not measurable within the scope and instrumentation accuracy of this study. The less direct effects of logging on species having extended fresh water stages in their life histories, such as steelhead trout and coho salmon, were not measured in this study.

SUMMARY

One of the first major timber harvests in Alaska began in the mid-1950's on Prince of Wales Island, providing an opportunity for study of some of the physical effects of logging on salmon stream habitat.

Three watersheds in the vicinity of Hollis, on Prince of Wales Island, were selected as the study area; about one-fourth of the Maybeso Creek watershed (total area, 15.2 square miles) and one-fifth of the Harris River watershed (31.8 square miles) were clearcut by high-lead cable logging methods.

Streamflow from the two logged watersheds did not change in comparison with nearby, unlogged Indian Creek. Similarly, Harris River showed no influence of clearcutting on the relationship between rainfall and peak flows. Likely changes in streamflow as a result of logging might have been detected if precipitation and streamflow had been measured with an accuracy of $\pm$ 2-3 percent. This accuracy was not approached.

Although sampled concentrations of suspended sediment for given levels of Harris River were higher during logging than before, these changes were not statistically significant.

Maximum increase in average monthly stream temperature at the gaging sites in Harris River and Maybeso Creek was 4° F. However, maximum observed temperatures appear to have increased up to 9° F. in the summer months. The temperature increase is believed to be associated with removing streamside timber. Although changes in winter stream temperatures resulting from logging are not conclusive, the data suggest that logging has little effect on the 32° to 34° F. temperatures that extend to spring.

Mapping and aerial photography indicated that logs and debris increased in Maybeso Creek during and after logging. This is probably due to logging of relatively high-volume timber and to poisoning of alder on the streambanks. A small increase in absolute number of logs and debris pieces occurred in Harris River during and after clearcutting. The initial number of pieces was small compared with Maybeso Creek and remained so during and after logging.

Clearcutting apparently did not adversely affect the salmon spawning habitat, based upon the returns of pink and chum salmon spawners to the study streams in the years during and after logging. An increase in numbers of spawners following clearcutting undoubtedly was associated with nonrelated factors. The greatest increases in summer stream temperatures occurred when pink and chum salmon spawning runs were just beginning to enter the systems in sizable numbers; somewhat higher stream temperatures in October and November conceivably could alter the normal incubation, emergence, and seaward migration of salmon eggs and fry, although supporting evidence is lacking. Increased amounts of logs and debris in the streams during and after clearcutting could reduce access to and amount of suitable spawning area; however, such barriers were not observed during the study.

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MASS WASTING

in coastal Alaska

Douglas N. Swanston

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INTRODUCTION

An understanding of erosion processes involving the downslope movement of earth materials is essential to the forest-land manager in Alaska. This has become increasingly clear in recent years with the apparent acceleration of slope erosion following large-scale clear-cutting of steep, timbered slopes in southeast Alaska. Erosion occurs primarily as soil mass movements associated with oversteepened slopes and high soil-water levels.

In 1961, a marked increase in slide activity associated with a period of high rainfall was observed in a number of recently logged areas. These observations brought about a survey of potential sliding in these areas. As a result of this survey, the principal sliding phenomena were identified and classified, and major factors contributing to their occurrence and distribution were evaluated (Bishop and Stevens 1964). Later work has concentrated on detailed investigations of landslide distribution, processes of movement, and factors affecting occurrence.

This paper summarizes and interprets the accumulated data and knowledge about slope erosion in southeast Alaska, particularly in relation to recently logged areas, with general suggestions and quidelines for prediction and control.

MASS WASTING, A DOMINANT EROSION PROCESS IN COASTAL ALASKA

Southeast Alaska is in an early stage of development both structurally and geomorphologically. Slopes are steep due to recent uplift and glacial activity. Many of them are above the angle of stability of natural soil materials.[1/] Soils on these oversteepened slopes are youthful, postdating the last major continental glaciation approximately 10,000 years ago. As a result, the soils are shallow, generally less than 3 feet thick, and coarse textured. Permeabilities are relatively high, and surface runoff on the slopes is minimal despite high rainfall (Patric and Swanston 1968; Swanston 1967b; Gass et al. 1967). Principal drainage is subsurface directly into main stream channels and major tributaries. The dominant natural slope erosion process under these conditions is "mass wasting"--the slow to rapid downslope movement of large masses of earth material of varying water content, primarily under the force of gravity.

CLASSIFICATION

Soil mass movements in timbered areas of southeast Alaska have developed under varying conditions of slope gradient, soil composition, and soil-water content. Some are the direct result of logging and logging road construction. The majority, however, are natural manifestations of mass wastage and slope reduction.

Dyrness (1967) described common classes of soil mass movements in the Coast Ranges and Cascades of western Oregon, based on mode of disturbance in a forested area. Many of these classes can be applied directly in southeast Alaska. Morphogenetically, mass movements in southeast Alaska range from rockfalls to mud flows, but the majority are classified as debris avalanches or debris flows involving the rapid downslope movement of a mixture of soil, rock, and forest debris with varying water content.[2/]

Mass movements caused by road fill failures, road backslope failures, and concentration of road drainage water are common; however, they are limited for the most part to small-scale soil slips and slumps. Large-scale mass movements in both recently logged and undisturbed areas are the most frequent and damaging. These involve debris avalanches and debris flows on steep valley sideslopes and narrow V-notch tributary drainages. These movements begin either as sudden rotations or translations of more or less intact masses of soil above an impermeable boundary and quickly revert to debris avalanches as stresses within the soil masses cause breakdown of soil structure.

[1/] The angle of stability referred to in this paper is that slope angle which equals the angle of internal friction. This is the angle at which the ratio between the driving forces due to gravity in a soil mass and the resisting forces due to friction equals unity. Simply, it is an indication of the shear strength of the soil mass due to interlocking of individual soil grains.

[2/] Slide classification used contained in National Research Council Highway Research Board Special Report 29, No. 21, "Landslides and engineering practice," edited by E. B. Eckel, 232 pp. 1958.

Downslope, a debris avalanche frequently becomes a debris flow because of substantial increases in water content.

OCCURRENCE AND DISTRIBUTION

Inspection of aerial photos of the Tongass National Forest, covering approximately 99 percent of the southeast Alaska land area, reveals evidence of widespread active mass wasting in timbered areas.[3/] More than 3,800 large-scale debris avalanches and flows have been counted, most having occurred within the last 150 years. Evidence of older sliding, predating the present old-growth forest, is masked from air photo identification but has been observed in the field in the form of buried soils and overturned profiles.

The most recent debris avalanches and debris flows are clearly identified by bare linear strips on valley sideslopes and in deep V-notch channels where soil and vegetation have been removed (fig. 1). Increasingly older avalanche and flow scars are identified successively by strips of pioneering species such as willow (*Salix* spp.) and alder (*Alnus* spp.) and finally by even-age stands of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) which are younger than the surrounding timber (figs. 2 and 3). Such

[3/] Landslide occurrence in coastal Alaska. Study No. 1604-12; data on file, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Juneau.

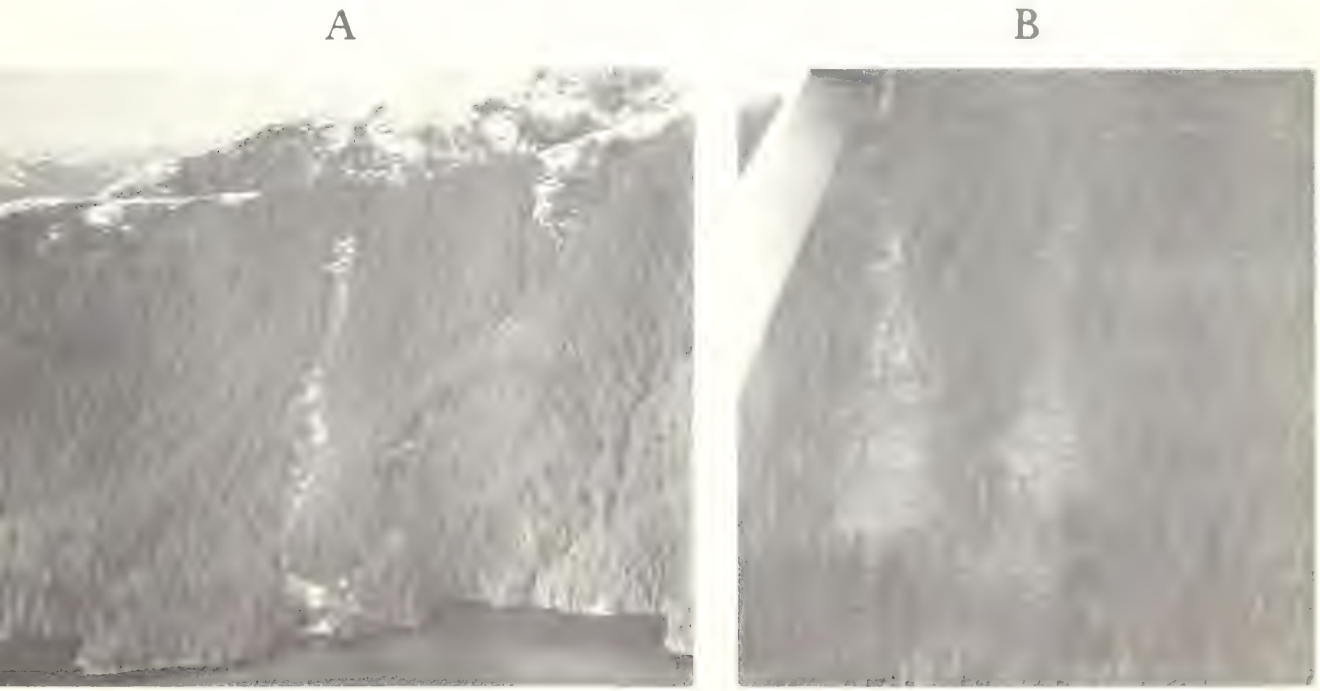

Figure 1.—Aerial views of recent debris avalanche-debris flow combinations on oversteepened slopes of southeast Alaska. A, Slide near Walker Cove, Behm Canal. A debris avalanche was apparently initiated by a rockfall from bluff directly above head of slide trace. Resultant debris flow lower on the slope carried debris directly to the sea. B, Two recent slides near Mirror Lake, Thorne Arm. In this case, much of the debris from the resultant flow has accumulated near the lower end of the slide trace.

Figure 2.--Older debris avalanche-debris flow traces showing successional regrowth of willow, alder, and Sitka spruce. A, Aerial view of two slide traces revegetated by alder near the head of Walter Island Arm, Port Houghton. B, View of lower slide trace on the south side of Blake Channel Narrows. Note successional regrowth starting with willow and alder in the foreground with spruce moving in behind.

Figure 3.--Old debris avalanche-debris flow traces along Bradfield Canal. Old slide areas (1) and (2), marked by even-age stands of Sitka spruce, are almost indiscernible, but can be picked up on aerial photos by noting the finer texture of the forest cover in the old slide trace. Note recent debris avalanche at right center of photograph.

successional regrowth on the older slide traces is easily recognized on aerial photos and provides a convenient means of estimating present stability and past sliding history of a slope. Snow avalanches which produce similar linear tracks on timbered slopes can be differentiated and eliminated from these estimates by observation of the following characteristics. If the track origin lies below the upper timbered boundary, it is probably a debris avalanche track. If the track extends above the timber boundary, it probably originated as a snow avalanche. Also, a snow avalanche produces little soil deposition at the slope base, and there is little or no soil removal in the slide track.

A study of the distribution pattern of these debris avalanches and debris flows reveals two areas of concentration. The largest area occurs south of the 57th parallel,

with principal concentrations on Revillagigedo and Prince of Wales Islands (fig. 4, area A). A second area occurs south of the 58th parallel, centered around Peril Strait on Baranof and Chichagof Islands (fig. 4, area B). Both areas coincide approximately with zones of maximum precipitation in southeast Alaska (Miller 1963).

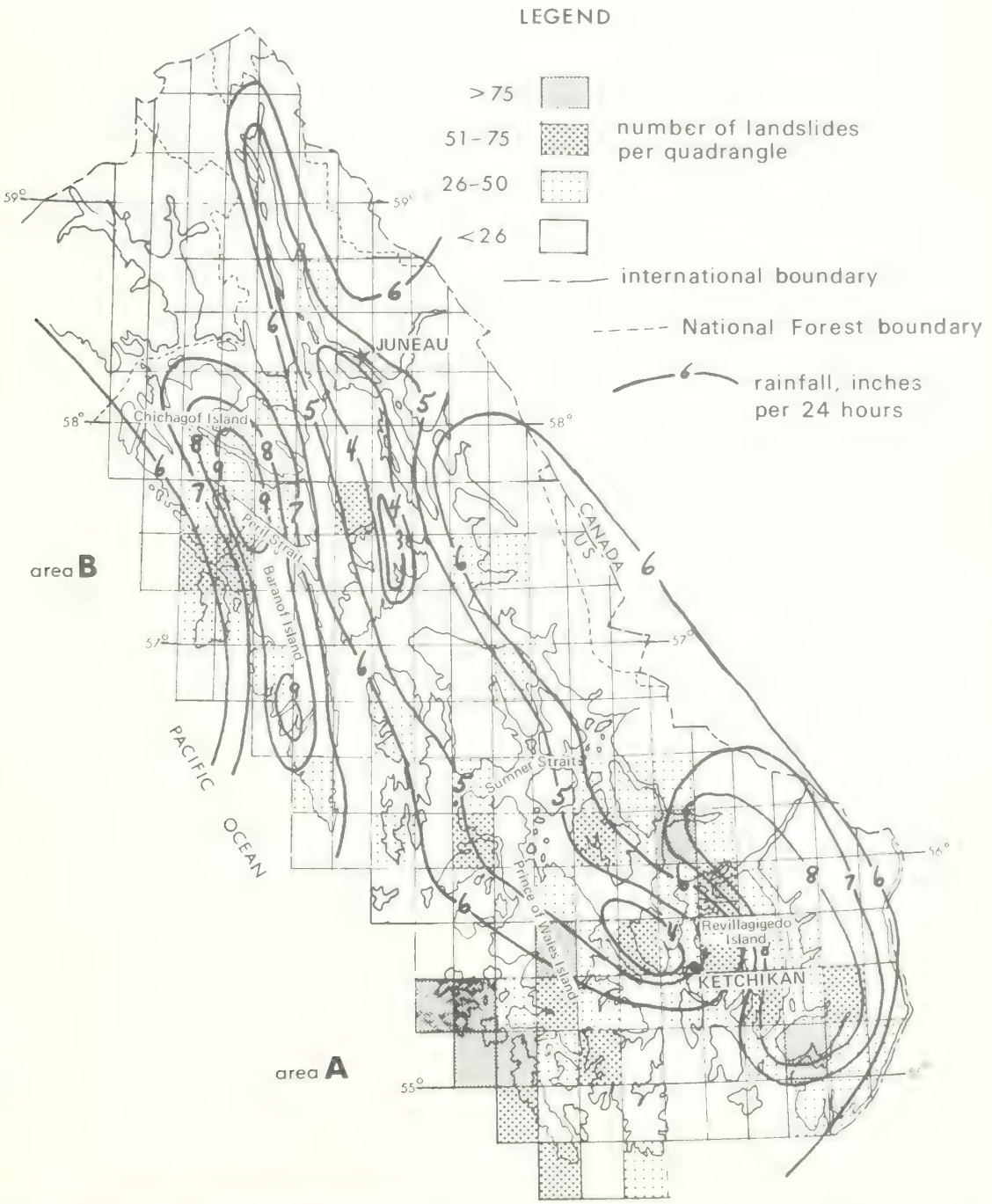

Figure 4.—Relation of landslide distribution to 5-year, 24-hour rainfall occurrence in southeast Alaska. Landslide occurrence expressed as number per 15-minute map quadrangle. Rainfall data adopted from Miller (1963).

Superimposed on this rough correlation of rainfall and slide occurrence is the effect of regional bedrock and glacial geology which modifies the effect of rainfall on landslide initiation through changing slope and soil characteristics. On the mainland and interior islands of the Alexander Archipelago (Revillagigedo, Etolin, Mitkof, Kupreanof, and Admiralty), the majority of debris avalanches and debris flows are developed in shallow, bedrock-derived soils[4/] with bedrock serving as the sliding surface. In this area, slopes are extremely steep, frequently more than the internal friction angle of the soil, due to vigorous erosion during the last continental glaciation. Glacial till deposits are thin or absent, due partly to the resistance of local bedrock (granite, diorite) to glacial erosion and partly to the distance of the area from major Pleistocene ice centers east of the Alaska-Canada Boundary Range. Conversely, many of the large-scale debris avalanches and debris flows, developed on the outer islands of the Alexander Archipelago, occur in soils derived from glacial till with compact, unweathered till serving as a sliding surface.[5/] In this area, more easily erodible bedrock (graywacke, black argillite) predominates, and local glaciations have deposited a thicker veneer of till, frequently extending to elevations of 1,200 to 1,300 feet. Slopes are less steep, although still at or near the internal friction angle on the upper slope, due to deposition of the till veneer over the steeper bedrock walls. Above the till limit and in areas of nondeposition of till, slides again occur predominantly in bedrock soils.

[4/] These soils belong to the Tolstoi series. They are shallow, well-drained soils of a very stony, silt-loam texture (particles below 2 mm. fall into the sandy silt range, according to the Unified Classification) developed from colluvium or fractured parent rock. Gravel content approaches 80 percent by weight. Depth to bedrock averages 12 inches.

[5/] These soils are podzols belonging to the Karta series. They are moderately well-drained, very gravelly loam soils (size fraction below 2 mm. falls into the silty sand category, according to the Unified Classification), derived from glacial till and overlying compact glacial till. Gravel content approaches 50 percent by weight. Depth to compact till varies from 15 to 60 inches but averages around 36 inches in the zone of slide initiation.

RELATIONSHIP OF DEBRIS AVALANCHES AND DEBRIS FLOWS TO SITE CHARACTERISTICS

Bedrock-Colluvial Soil Slides

Debris avalanches and debris flows developed in shallow bedrock-derived or colluvially derived soils are the most frequently occurring natural soil mass movements in southeast Alaska. Observations in active slide areas with soils of this type (Bishop and Stevens 1964, Swanston 1967a, Swanston[6/]) indicate that the slopes on which these slides commonly develop are extremely steep,

[6/] Swanston, Douglas N. Geology and slope failure in the Maybeso valley, Prince of Wales Island, Alaska. 1967. (Unpublished Ph. D. dissertation on file at Mich. State Univ., East Lansing.)

lying between 40° and 60° (88- to 133-percent grade) and support mature forests of Sitka spruce and western hemlock. The soils are coarse and very permeable with a high proportion of angular rock fragments and some organic material. The soils are mechanically cohesionless, although Stephens (1967) reports the presence of unusually large amounts of organic material which may provide substantial "secondary" cohesion.

These debris avalanches and debris flows begin characteristically on open slopes, frequently related to local drainage concentrations, and generally clear the slide trace of soil and vegetation to bedrock for the entire length of the slope (fig. 5). The movement is translational, beginning with failure of a small mass of soil along an impermeable bedrock surface and spreading outward and downward in a wedge-shaped path (type B, fig. 6). In all active slide areas which were investigated, the underlying bedrock surfaces either dipped into the valleys or were smoothed by glacial erosion, providing little natural obstruction to downslope movement of soil under the force of gravity.

Figure 5.—Combination debris avalanche-debris flows developed in bedrock-derived soil (Tolstoi). A, Martin Creek valley, Bradfield Canal. View toward valley floor from center of slide trace, showing extensive debris flow deposit at base of slope which has broken through the trees at several points to deposit broken timber and other debris in small muskegs beyond. Note shallowness of soil typical of this type of landslide. Glacially rounded dioritic bedrock is exposed by complete removal of the soil layer in the slide trace. B, Maybeso Creek valley. Slide initiated by rockfall from bluff above slide head.

A

B

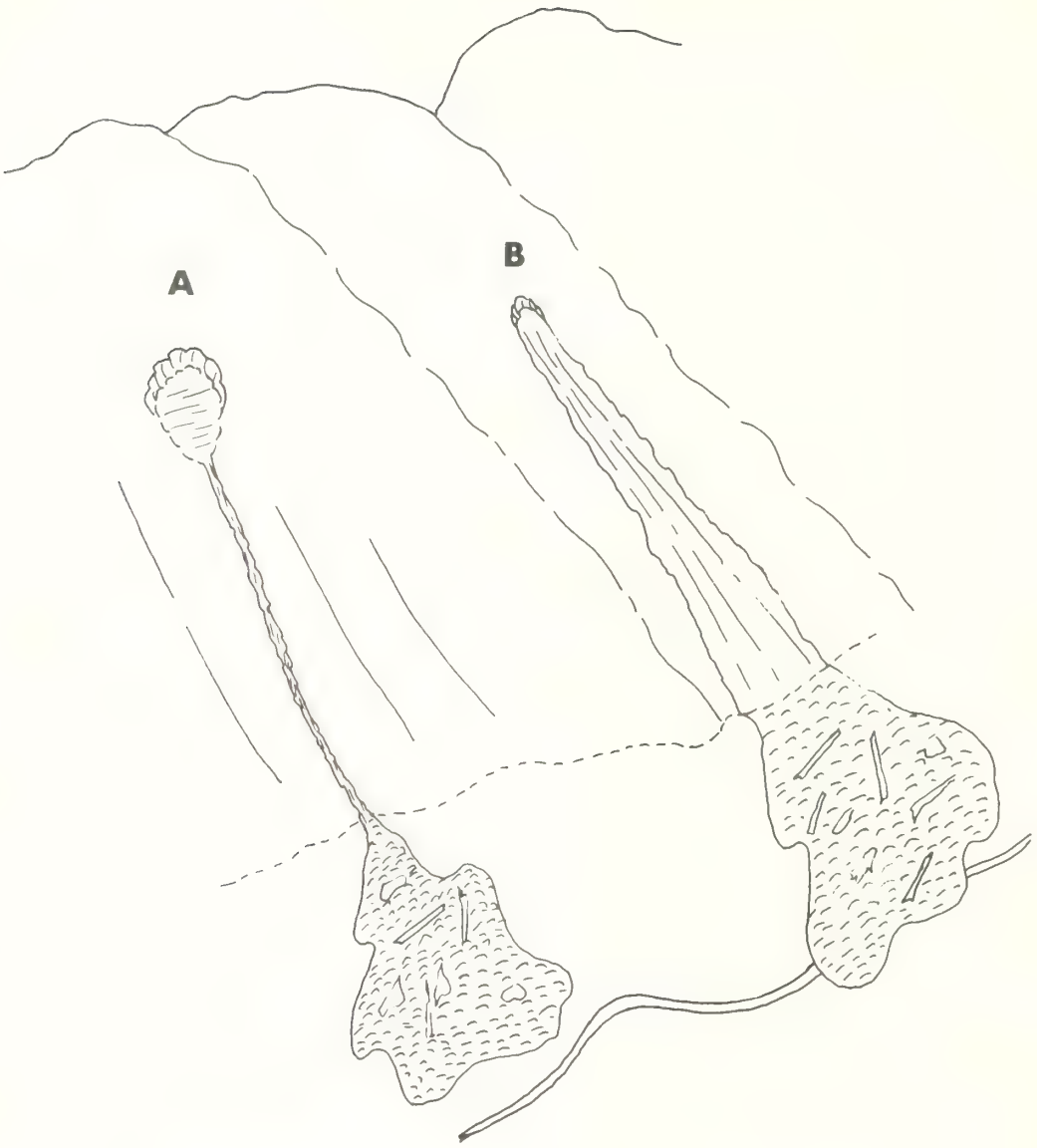

Figure 6.—Representative diagram of debris avalanches and debris flows on a glacially oversteepened slope.

A. Debris avalanche-debris flow combination developed on a till-covered slope. Note typical spoon-shaped configuration in zone of initial failure with sliding material more or less confined within a narrow zone until it reaches the valley floor.

B. Debris avalanche-debris flow combination developed in bedrock-derived or colluvial soil. Note the characteristic wedge-shaped trace expanding toward the slope base.

Slope angles in the slide initiation zone characteristically exceed the probable angle of internal friction of coarse-grained soils of the Tolstoi type. The internal friction angle varies from 27° to 35° for well-graded silty sands and from 34° to 46° for loose sands, the actual value depending on soil density and weight of overlying material (Terzaghi and Peck 1962). Although laboratory analyses have not been made, the actual internal friction angle of the Tolstoi soil probably lies at the upper end of the silty sand range, based on its relative content of coarser particles and apparent lack of preconsolidation. The effect of the overlying forest weight is largely negated since most of the weight is carried by roots passing through the soil and lying on the bedrock surface.

The balance between slope stability and failure is critical on these slopes. The anchoring effect of root growth through the thin soil and into joints and fractures in the bedrock probably increases the stability of these soils somewhat, as does the cohesion provided by organic colloids. The effectiveness of these stabilizing factors, however, may be reduced during periods of high rainfall by development of seepage and pore-water pressures associated with rising soil-water levels. With the bedrock-derived soils in their least stable condition, only a small triggering force is required to cause total failure and rapid downslope movement of the soil mass. Such a force can be produced by sharp increases in soil-water content, rapid increase in soil mass, and direct destruction of stabilizing root mass. Field observations indicate that the latter two, resulting from tree blowdown, dynamic loading of the soil mass by wind forces acting on the tree cover, and rapid addition of rock masses by direct fall, are the principal causes of sliding on unlogged slopes (Swanston 1967a).

Till Soil Slides

Debris avalanches and debris flows in glacial till soils on valley sideslopes frequently begin within linear seepage depressions that dissect the till deposits (fig. 7). These depressions were originally formed as consequent drainage channels[7/] by surface runoff after retreat of glacier ice from the valleys. Since glacier retreat, a shallow podzol soil has developed in the channels and on the surrounding till slopes. At present, the soil in the depressions serves as a center of concentration for soil-water seepage. Surface runoff occurs in the depressions only during periods of extremely high rainfall when the till soil becomes saturated. The occurrence of buried soils, overturned profiles, and buried organic lenses in the lower end of these depressions indicates a past history of active sliding and suggests that, at present, the depressions enlarge themselves chiefly in this manner.

The soil in which the slides develop is well-drained podzol, 1 to 3 feet thick, above compact, unweathered till. The movement is rotational with the impermeable, unweathered till surface serving as the lower limit of sliding. The slide trace characteristically exhibits a spoon-shaped

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7/ Consequent drainage channels are those formed as a direct consequence of the original slope of the surface on which they developed. A new runoff channel formed as a consequence of till deposition on the slope.

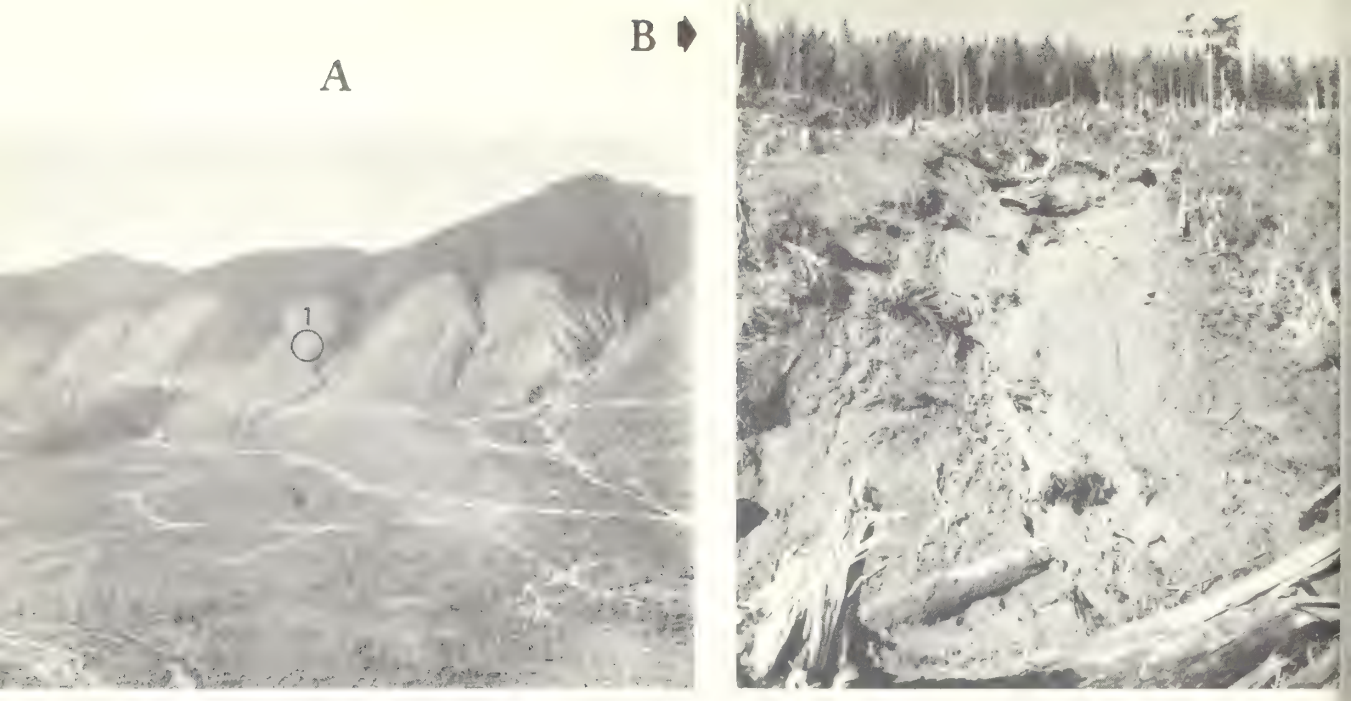

Figure 7.—Combination debris avalanche-debris flows in a glacial till soil (Karta), Maybeso Creek valley, Prince of Wales Island. A, Aerial view of dissected till-covered slope where active sliding is occurring. Recent sliding, directly correlated with a period of high rainfall and resultant concentration of soil water, has occurred to the right of the leave strip in the center of the photo (1). These are probably associated with clearcutting, but there is also much evidence of prelogging slide occurrence. B, Closeup view of slide at site 1. Note the shallowness of the slide trace. The unweathered till which served as the sliding surface is exposed in center foreground as a lighter soil zone next to the long-butted stump. The weathered till or Karta soil is the darker material above it.

configuration in the zone of initial rotational failure, with the slide material more or less confined within a narrow channel before reaching the valley floor (type A, fig. 6). The slides begin on 34°-40° slopes, with most common occurrence on slopes at or near 37°. This angle corresponds to the laboratory-determined angle of internal friction of the till soil obtained from samples taken in the Hollis area.[8/]

Excess soil water is probably the principal factor in triggering these till slides. Soil permeability is good,[9/] with subsurface flow concentrated above the unweathered till surface. During periods of extremely high rainfall following initial saturation of the soil, excess soil water produces a rising piezometric level. At saturation, maximum soil-water levels produce active pore-water pressures great enough to substantially reduce shear resistance of the soil. Studies relating rainfall to piezometric rise in the Maybeso Creek valley verify this. During the period of most recent sliding in 1961, the till soils with debris avalanches and flows were saturated. The resultant active pore-water pressures reduced the soil shear strength by as much as 60 percent.

[8/] Undisturbed pedestal samples tested by triaxial shear at the Civil Engineering Laboratory, Michigan State University, had an effective angle of internal friction (ϕ) of 37° and an effective cohesion (C) of 0.

[9/] Unpublished field data from pumping tests at Hollis indicate a permeability range from 1.68 to 1.3 inches per hour.

These shallow till soils become saturated during storms with rainfall intensities in excess of 5 inches in 24 hours, an unusually high intensity with a 2- to 5-year-occurrence frequency in southeast Alaska (Swanston 1967b).

Although these till soils are physically cohesionless (see footnote 8), other factors combine to create a shear-resistant force--an "apparent cohesion"--that cannot be accounted for directly in soil physical properties. Part of this force may be a secondary cohesion produced by adhesion of organic colloids in the soil. Stephens (1967) has described an abnormally high organic colloid content for these till soils and attributes their surprisingly low bulk densities to its effect. Partial stabilization of the slide-prone soil masses is also produced by the anchoring of root masses through the soil and into the unweathered till (Patric and Swanston 1968; unpublished field data[10/]). Stump excavations indicate that the tree root patterns on these oversteepened slopes consist of widely spread lateral roots lying along the unweathered till surface with sinkers penetrating into the upper 6-12 inches of partly weathered till at the B-C interface. Destruction of these root sinkers, by windthrow or decay following cutting, may substantially increase the susceptibility of these slopes to sliding.

Windthrow occurs frequently in southeast Alaska forests and has been correlated directly with debris avalanche and flow occurrence on soils derived from bedrock or colluvium (Swanston 1967a). Whether root decay following cutting causes increased susceptibility to landsliding is more difficult to determine. Bishop and Stevens (1964) observed a 4- to 5-year time lag in increased slide activity following logging on both types of soils which they related to a possible loss of root systems as "strength builders--retainers" in the soil mantle. Laboratory examination (see footnote 10) of stump laterals sampled from cuttings of different ages scattered throughout southeast Alaska support this observation. Tests of shear strength perpendicular to the grain on lateral roots greater than 1 inch in diameter reveal a very gradual decrease in shear strength with time since cutting. No signs of decay were observed on samples from cuttings less than 4 years old. Decay[11/] was apparent almost universally on samples from stumps older than 4 years, frequently penetrating the root surface to a depth of one-half inch.

Evidence of soil creep in the form of catsteps, turfrolls, overturned soil profiles, and recurved tree trunks is abundant on oversteepened slopes. However, creep studies in the till soils have so far failed to show any direct relationship to occurrence of debris avalanches and flows. Quantitative creep measurements made in the Hollis area in 1966 and 1967, however, indicate that movement does occur, primarily in the first 6 to 12 inches of soil, and that the rate decreases rapidly toward the unweathered till surface. The soil appears to be moving as a flowing mass with no well-defined shearing planes. The maximum rate of movement is

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[10/] Tree rooting and soil stability in coastal forests of southeastern Alaska, Study No. FS-NOR-1604:26; on file at the Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Juneau.

[11/] The fungi [illegible]

approximately one-fourth inch per year.[12/] [13/] Such movement undoubtedly produces a stress buildup in the soil over a period of time and may considerably increase slide susceptibility of the soil in critical areas.

Debris Torrents

Debris avalanches on extremely steep (40°-60°) sideslopes of deeply incised, steep-gradient stream channels or V-notch ravines are common to both soil series and occasionally produce massive debris flow and torrent flow deposits in the valley bottoms (Bishop and Stevens 1964).

The debris avalanches begin in shallow soils developed in colluvium or glacial till. The slope gradients involved are far greater than the angle of internal friction of the particular soil, greatly intensifying any factors tending to reduce stability. The slopes are extremely unstable and on the verge of failure at all times. Downslope stress on the soil is increased due to the weight of added water during periods of high rainfall. Increased pore-water pressure or destruction of stabilizing root systems aggravates the condition and may initiate sliding, as may bank undercutting near a stream. Usually these slides have short runs, beginning at the tops of valley sideslopes and ending at the streams (figs. 7 and 8).

Figure 8.—Debris avalanches in steep-walled V-notch drainages. A, In till soil, Maybeso Creek valley. B, In bedrock-derived soil, Neets Bay. Note the masses of small roots overhanging the headwall of the slide. Many still remain firmly attached to the fractured and jointed bedrock substrata.

12/ (a) Barr, D. J. Report of activities and results of the soil creep study (FS-NOR-1604:13), June-November 1965, Hollis, Alaska. (b) Barr, D. J. Report of the movement-measurement phase of of the Landslide Triggering Study (FS-NOR-1604:17). Both reports on file at the Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, Juneau.

13/ Barr, D. J., and Swanston, D. N. Measurements of creep in a shallow, slide-prone till soil. (In preparation for publication, Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Serv., Portland, Oregon.)

If the amounts of material are sufficient, they may become debris flows upon reaching the streams as a result of increased water content. More frequently, the debris is simply carried away as increased sediment load in the stream. Rapp (1961) in Scandinavia and Bishop and Stevens (1964) in southeast Alaska describe a phenomenon associated with this kind of flow resulting from debris avalanche accumulations in the bottoms of steep-sided channels. Debris forms a dam across a stream at the base of an avalanche. Subsequent material from upstream avalanches accumulates behind this barricade (fig. 9). When the dam gives way, a large volume debris flow or debris torrent occurs (fig. 10).

Figure 9.—Natural dam across V-notch drainage produced by accumulation of forest debris. Upstream debris-avalanching produces a buildup of soil and organic debris behind the dam which, when released, produces a large-scale debris torrent.

Figure 10.—Torrent flow deposit (center foreground) produced by failure of debris dam within the timber in center V-notch.

CONCLUSIONS AND RECOMMENDATIONS

Mass wastage is the dominant process of natural erosion and slope reduction in geologically youthful southeast Alaska. Steep slopes and excessive soil-water content are the principal causes of slide occurrence; destruction of natural slope equilibrium and stabilizing root systems are secondary factors.

Slope gradient alone characterizes the region as primed for mass movements of all types. Sections of almost every timbered slope exceed the natural angle of stability of the soil on them.

With the high rainfall of the region and resultant, almost continuous, saturation of the soils, these oversteepened slopes become particularly sensitive to events tending to disrupt their delicately balanced stability. Excess soil water, directly related

to high intensity storms, is one such factor which causes instability in till soil areas, and it may be equally important in areas covered by colluvium or bedrock-derived soils. Natural catastrophic events such as rockfalls and tree blowdowns are also closely related to debris avalanche and flow occurrence in these oversteepened slopes, particularly in areas of colluvium or bedrock-derived soils.

Man's activities will aggravate such naturally unstable slope conditions. Therefore, the practical problem faced by land managers is the decision to accept the consequences of logging oversteepened slopes or to control the effects of these activities in order to minimize the occurrence of mass movements. Control may be done by application of direct methods of slope stabilization or avoidance of areas of known or expected instability.

At present, known slope stabilization techniques are not being applied extensively in southeast Alaska, but they may be in the near future as timber values increase. These techniques include (1) artificial drainage of the soil in slide-susceptible areas to reduce pore-water pressure, (2) removal of overburden to reduce shear stress in the soil, and (3) improvement of shear strength characteristics of the soil in hazard areas by the maintenance of living root systems which anchor through the soil and into the substratum. Soil drainage would involve placement of soil drain tile, construction of drainage ditches or, in some critical areas, artificial grouting of hazardous slopes to divert subsurface water concentrations. Overburden removal involves extensive heavy equipment operation. Root stabilization in areas of maximum instability would require maintenance of timber strips, parallel to and including the unstable areas, with a wide enough lateral spread to reduce windthrow hazard.

Probably the most practical and direct management policy at present is avoidance of areas of maximum slide susceptibility. The lower limit of internal friction angles for soils commonly found on these slopes is known ($\sim 34^{\circ}$). Slopes with gradients equal to or greater than this angle are highly susceptible to sliding, particularly if they are severely disturbed. With this information, general areas of maximum instability can then be identified. On aerial photos, these areas can be delineated by the occurrence and concentration of old debris avalanche and flow scars. A more accurate identification can be made from a slope-gradient map, which is constructed from scale measurements of slope angles on the aerial photographs and related topographic maps. A slope-gradient map can be used to (1) delineate potential slide areas, (2) determine percentage of slide-prone ground in the total area under consideration, and (3) establish cutting patterns which will best utilize these areas with minimum disturbance. Areas of imminent slide hazard, lying above a critical contour corresponding to the estimated angle of stability, should be given special management considerations.

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Mass wasting, a dominant form of erosion in coastal Alaska, is common where slopes are oversteepened by glacial erosion, soils are newly developed and shallow, and there is abundant rainfall. Presently, the most practical policy for the forest-land manager is avoidance of susceptible areas during timber harvest. Old debris avalanche and flow scars are visible on aerial photos, but a more accurate identification of these areas can be made from a slope-gradient map, which can be used to (1) delineate potential slide areas, (2) determine percentage of slide-prone ground, and (3) establish cutting patterns causing minimum disturbance.

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Headquarters for the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is in Portland, Oregon. The Station's mission is to provide the scientific knowledge, technology, and alternatives for management, use, and protection of forest, range, and related environments for present and future generations. The area of research encompasses Alaska, Washington, and Oregon, with some projects including California, Hawaii, the Western States, or the Nation. Project headquarters are at:

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Projected Developments of the Timber Economy of the Columbia - North Pacific Region

by

Brian R. Wall

OCT 23 1969

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE PORTLAND, OREGON

Errata

Wall, Brian R.
1969. Projected developments of the timber economy of the Columbia-North Pacific Region. U.S.D.A. Forest Service Res. Pap. PNW-84, 87 pp. Pacific Northwest Forest and Range Experiment Station.

The following tables should be changed to reflect a correction in projected logging employment for the year 1980 in western Montana.

New Data

Table 13, page 31	(Year 1980) (No. of persons)
Subregion 1 -- Lumber and wood products	10,811
Subregion 1 -- Total	11,733
Total C-NP Region: Lumber and wood products	102,729
Total C-NP Region: Total	135,909

Table 14, page 32	(Year 1980) (No. of persons)
Subregion 1 -- Montana	5,612
Subregion 1 -- Total	10,811
State Total -- Montana	5,612
Grand Total	102,729

Table 17, page 35	(Year 1980) (Thousand dollars)
Subregion 1	82,207
Total	781,151

Table 42, page 71	(Year 1980) (No. of persons)
Western Montana: Lumber and wood products	5,612
Western Montana: Total	6,183
Total C-NP Regions: Lumber and wood products	102,729
Total C-NP Regions: Total	135,909

Table 48, page 77	(Year 1980) (No. of persons)
Subregion 1, Logging	1,435
Subregion 1, Total	6,183

Cover photo: The Diamond National Corp. sawmill at Albeni Falls, Idaho, on the Pend Oreille River behind Albeni Falls Dam. This mill produces about 60 million board feet of lumber each year. Just upriver lies the Idaho-Washington boundary.

SUMMARY

The forest industries of the Columbia-North Pacific Region have been developing for more than a century. Today, they are a major component of the Region's economy, and their products are distributed throughout the Nation and the world. The projections indicate the forest economy will continue to be a significant element of the regional economy for many years. The forest industries will necessarily consume increasing amounts of second-growth roundwood during these years. The future levels of timber harvest, which would be required by the projected industrial development, are based on the assumption that forest-land owners, both public and private, would continue to increase their investments in forestry.

The mix of forest industries is projected to change over time, resulting in decreasing wood consumption by the lumber industry and increasing wood consumption by veneer, plywood, and pulp and paper industries. Forest industrial employment will decline as worker productivity increases. Payrolls in the forest industries will increase, reflecting gains in productivity and continuing demands for skilled labor.

The future forest economy will depend on young timber stands such as this one in Lane County, Oregon.

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LEGEND

Subregion boundaries for economic studies

SUBREGIONS

1. Clark Fork - Kootenai - Spokane
2. Upper Columbia
3. Yakima
4. Upper Snake
5. Central Snake
6. Lower Snake
7. Mid Columbia
8. Lower Columbia
9. Willamette
10. Coastal
11. Puget Sound
12. Oregon Closed Basin

COLUMBIA-NORTH PACIFIC REGION

FEBRUARY 1966

Figure 1.–Map of Columbia-North Pacific Region by subregion, State, and county.

INTRODUCTION

This report has been prepared by the Pacific Northwest Forest and Range Experiment Station as part of the contribution by the Forest Service, U.S. Department of Agriculture, to comprehensive river basin planning by the Water Resources Council and cooperating agencies.

The report contains data on the timber resource and forest industries, and it presents projections of wood consumption and forest-based employment and payrolls in the Columbia-North Pacific Region (C-NP Region) to the year 2020. These projections are based on the local timber supplies and projections of national demand for timber products. Current and projected estimates are presented for the 12 individual subregions and for the entire Region.

Figure 1 shows the Columbia-North Pacific Region divided into the 12 subregions established for economic studies. These subregions conform generally to hydrologic land-use boundaries, except that they are identified by county rather than watershed boundaries.

Much of the background for this report has come from four recent studies. The national perspective was supplied by "Timber Trends in the United States" (U.S.D.A. Forest Service 1965).[1] The regional background and projection methodology came, in part, from a report titled "Prospective Economic Developments Based on the Timber Resources of the Pacific Northwest" (Gedney et al. 1966) and prepared by the Forest Service for the Bonneville Power Administration. The preparation of two other reports on river basin development, "Prospective Timber Supplies and Forest Industrial Development in the Willamette River Basin" and "Prospective Timber Supplies and Forest Industrial Development in the Puget Sound Basin and Adjacent Waters,"[2] provided experience and methodology in analyzing the forest economy on the subregional level. These last three reports were prepared by the Pacific Northwest Forest and Range Experiment Station.

The resource statistics developed for the Columbia-North Pacific Region in this report differ from those in the previous reports because new and updated inventory data have become available, new trends in timber demand have become apparent, and revised cutting budgets have been developed by public agencies. In addition, some differences arise from the fact that the boundary definitions of the Region and subregions differ slightly from previous reports. The forest inventory data presented here for Oregon and Washington have been prepared by the Forest Survey Project of the Pacific Northwest Forest and Range Experiment Station. The Forest Survey Project of the Intermountain Forest and Range Experiment Station has prepared the inventory statistics for Idaho, western Montana, and Wyoming. The statistics meet the Forest Survey standards of accuracy.

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[1] Names and dates in parentheses refer to References, p. 39

[2] Wall, Brian R. Prospective timber supplies and forest industrial development in the Willamette River Basin. 1965. (Unpublished Pacific Northwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Admin. Rep., 69 pp., illus.)

Wall, Brian R. Prospective timber supplies and forest industrial development in the Willamette River Basin (supplemental projections of forest industry employment and roundwood consumption – 1963-2020). 1966. (Unpublished Pacific Northwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Admin. Rep., 9 pp.)

THE PRESENT FOREST RESOURCE

The Columbia-North Pacific Region has a land area of 169 million acres, 7 percent of the total land area of the United States. It contains 85 million acres of forest land, 11 percent of the Nation's total, and 70 million acres of commercial forest land, 14 percent of the national total. Of the 15 million acres of noncommercial forest land in the Columbia-North Pacific Region, 5 million acres are of commercial character but in areas reserved for use as National Parks;[3] wild, wilderness, and primitive areas; and State, county, and municipal parks. The remaining 10 million acres of noncommercial forest land are unsuitable for raising commercial timber crops because of their low productivity due to factors such as high altitude, low rainfall, and steep terrain (table 1).

The forests of the Columbia-North Pacific Region are divided into three broad areas on the basis of differing physiographic and climatic conditions: the Douglas-fir region, the ponderosa pine region, and the northern Rocky Mountain region.

The Douglas-fir region of the C-NP Region includes all of western Washington

[3]Does not include changes in National Parks, wilderness areas, etc., created since January 1, 1966.

Table 1.—Land area in the Columbia-North Pacific Region and the United States, by major class of land

Type of land	Columbia-North Pacific Region, January 1, 1966		United States[1]
	Thousand acres	*Percent of U.S. total*	*Thousand acres*
Commercial forest land	70,248	14	508,845[2]
Noncommercial forest land:			
Productive reserved	4,603	29	16,008
Unproductive	10,211	4	234,012
Total	14,814	6	250,020
Total forest land	85,062	11	758,865
Total nonforest land	84,284	6	1,512,478
Total land area	169,346	7	2,271,343

[1]From "Timber Trends in the United States," January 1, 1963 (U.S.D.A. Forest Service 1965).

[2]Not included are the approximate 320,000 acres of forest land in Puerto Rico and some parts of interior Alaska for which data are not yet available.

and western Oregon. On the west, it is bounded by the Pacific Ocean and on the east by the summit of the Cascade Range. Here, climatic conditions are very favorable to conifer forest growth, and, as a result, the region is characterized by its dense stands of tall trees. Douglas-fir is the dominant tree species except for spruce and hemlock in the more humid areas along the coast and true firs at the higher elevations of the Cascade Range.

The ponderosa pine region lies east of the Cascade Range in Washington and Oregon. Here, the climate is much drier than in the Douglas-fir region. There are two timberlines which limit the extent of the forest-land area on the east side. As on the west side, there is a timberline associated with the severe climatic conditions at high elevations. The other timberline is associated with arid conditions, and it can be referred to as the "dry" timberline. The Cascade Range is an effective barrier to the moisture-laden westerly winds from the Pacific Ocean. As a result, extensive areas of eastern Washington and eastern Oregon have a low precipitation at lower elevations below which forests cease to grow due to the lack of moisture. The timber zone, then, lies between these two timberlines and is generally confined to the more mountainous areas where sufficient moisture and suitable climate are available to sustain forest growth.

The eastern Oregon and eastern Washington area is generally referred to as the ponderosa pine region because it is characterized by extensive stands of ponderosa pine which occur at low elevations above the "dry" timberline. At higher elevations, the pure stands of pine give way to mixed stands of Douglas-fir, western larch, white fir, and lodgepole pine. In the cool moist areas of higher elevations, noble fir, Engelmann spruce, subalpine fir, western hemlock, and white pine are found.

The third major part of the Columbia-North Pacific Region lies to the east in Idaho, western Montana, and Teton County, Wyoming. Like the ponderosa pine region, this portion has extensive semiarid nonforest areas, especially in southern Idaho which is only 30 percent forested. In the north, there are extensive forested areas stretching west from the Continental Divide in western Montana through northern Idaho into eastern Washington. From the standpoint of volume yields, timber quality, and operability, the best timber in the Rocky Mountains is found in northern Idaho and western Montana (Pissot and Hanson 1963).

Both northern Idaho and western Montana are 80 percent forested, and have large areas in Douglas-fir, ponderosa pine, lodgepole pine, and fir-spruce type. Northern Idaho, in addition, has a substantial acreage of western white pine type and western Montana a large area of western larch type. Although the northern subregions in this area have a history of severe forest fires which have left substantial areas of nonstocked and poorly stocked lands, undoubtedly the greatest stocking problem in the forests of this area is overstocking. Both understocked and overstocked conditions will reduce yields in the foreseeable future.

Softwood species are most common

Softwood species types dominate the forests of the Columbia-North Pacific Region, accounting for 92 percent of the commercial forest area (table 26, page 47). The most common softwood species type is Douglas-fir, which covers 26.8 million acres of commercial forest land and is found in every subregion (table 27, page 48).

The ponderosa pine type covers the second largest area of commercial forest land in the C-NP Region. Like Douglas-fir, it occurs in every subregion, but its importance is negligible in western Oregon and western Washington.

The fir-spruce forest type is composed of several associated forest species: Engelmann spruce, grand fir, subalpine fir, and other true firs. As a group, these species

cover 8.5 million acres of commercial forest land in the region, but they are most significant in the Idaho-western Montana area (table 27, page 48). These species are grouped because they frequently occur in mixture and are utilized similarly for lumber and pulpwood.

Lodgepole pine is found in every subregion of the C-NP Region. It is the predominant species on 7.5 million acres of commercial forest land, but its utilization has been largely limited to the inland area with some lumber, poles, and piling being produced from it. For the future, it offers a vast untapped resource for uses such as pulp production.

Hardwood forest types cover only 6 percent of the commercial forest land (4.4 million acres) in the Columbia-North Pacific Region (table 26, page 47). Ninety-two percent of the hardwood area occurs west of the Cascades, where it frequently is found on the better growing sites. In many areas, hardwoods are the first tree species to enter naturally after the forest has been disturbed by fire or logging. About one-half of the hardwoods in western Oregon occur in the five southwestern counties. In the inland portion of the C-NP Region, the hardwoods are generally associated with moist valley bottoms bordering streams.

Federal ownership most important

The largest public forest holdings in the Columbia-North Pacific Region are in National Forests with 51 percent (36 million acres) of the commercial forest area (table 28, page 51). East of the Cascades, the National Forests are the dominant ownership, whereas in the subregions west of the Cascades, National Forests represent a smaller proportion of the total. As shown in the following tabulation, the proportion of total commercial forest land area in National Forest ownership ranges from 88 percent in the Upper Snake subregion to 26 percent in the Puget Sound and the Coastal subregions in western Washington and western Oregon:

	Percent
Subregions east of the Cascades:	
Upper Snake	88
Central Snake	80
Oregon Closed Basin	76
Lower Snake	74
Mid-Columbia	62
Clark Fork-Kootenai-Spokane	59
Upper Columbia	42
Yakima	38
Subregions west of the Cascades:	
Willamette	40
Lower Columbia	30
Coastal	26
Puget Sound	26

The Bureau of Land Management has commercial forest land in every subregion and holds the fourth largest acreage of commercial forest land in the Columbia-North Pacific Region (table 28, page 51). It is a major timber owner in western Oregon, especially in the Coastal subregion where it has 1.6 million acres of commercial forest land under management.

Indian-owned lands, managed by the Bureau of Indian Affairs, account for 3 percent (2.4 million acres) of the commercial forest land in the C-NP Region (table 28, page 51). The Indian timber resources in the larger reservations are important to the economies of several subregions even though they lack major importance in the whole Northwest. For example, the Yakima Indian Reservation accounts for about 28 percent of the commercial forest land in the Yakima subregion. The Colville and the Spokane Indian Reservations are important to the forest economy of northeastern Washington in the Upper Columbia subregion where they account for 30 percent of the commercial forest land.

Other public agencies own 6 percent of the commercial forest land

The other public owners include the States, counties, and municipalities, and as a group they account for 4.4 million acres of commercial forest land in the Columbia-North Pacific Region (table 28, page 51). The State of Washington is the largest owner in this group with 2 million acres of commercial forest land under management, and it ranks fourth in State ownership of commercial forest land in the United States.

Thirty-four percent of the commercial forest land is held by private owners

Private owners hold 24 million acres or 34 percent of the commercial forest land in the Columbia-North Pacific Region (table 28, page 51). In the Douglas-fir region of western Oregon and western Washington, private ownership accounts for about half of the commercial forest land. Forest industrial owners manage 55 percent of the 13.2 million acres of private commercial forest land. Lumber companies are the most important industrial ownership with 4.6 million acres of commercial forest land, and pulp and paper companies rank second with 2.4 million acres. Farmers own 2.5 million acres of the commercial forest land west of the Cascade Range. Miscellaneous private owners as a group hold 3.4 million acres of commercial forest land. Many of the large owners, such as railroads, actively manage their lands for timber production. However, many of the small miscellaneous private owners in the Douglas-fir region do not actively manage their forest lands because they are not timber oriented.

In the ponderosa pine region, including Klamath County,[4] Oregon, private owners account for 31 percent of the total commercial forest land (6.2 million acres). Farmers are the largest private owner group in this region, with 54 percent of the private ownership or 3.4 million acres. The lumber industry owns the next largest area of private commercial forest land (about 2 million acres). The industrial owners in this area own some of the finest stands of ponderosa pine in the Columbia-North Pacific Region (Pacific Northwest Forest and Range Experiment Station 1965).

In all of Idaho, including Oneida, Franklin, and Bear Lake Counties,[5] private owners account for 20 percent of the State's commercial forest land (3.2 million acres). Industrial and other private owners (excepting farmers) manage about 60 percent of the private commercial forest land, whereas the farmers own the remainder. Private interests claimed the best timberlands, especially the white pine forests, in northern Idaho, during the late 19th century. As a result, 81 percent of the private forest land (2.6 million acres) in Idaho is found in the northern part of the State.

In western Montana, 27 percent of the commercial forest land (2.8 million acres) is privately owned. Miscellaneous private owners, including large mining interests and railroads, hold 46 percent of the private forest lands (1.3 million acres). The lumber industry is the second largest private owner in western Montana with 37 percent of the private commercial forest lands (1.0 million acres) and farmers are the smallest ownership group (471,000 acres).

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[4] These ownership statistics concerning the forest resource are available only for larger areas, including Klamath County, Oregon, and Oneida, Franklin, and Bear Lake Counties, Idaho. Although these counties are not included in the C-NP Region, their inclusion does not materially affect the relations developed.

[5] Oneida, Franklin, and Bear Lake Counties are outside the boundaries of the C-NP Region in this study.

Columbia-North Pacific forest land has high productive capacity

Although the 70.2 million acres of commercial forest land in the Columbia-North Pacific Region represent only 14 percent of the Nation's commercial forest area, the Region has 43 percent (about 19 million acres) of the Nation's forest land rated as potentially most productive. These are lands which are capable of yielding 120 or more cubic feet per acre per year (table 2). These high-site lands are mostly found in the Douglas-fir region where the climate is moist and favorable for forest growth. Sixty-one percent of the Douglas-fir region's forest lands are in this productive class. In general, the eastern portion of the C-NP Region has forest lands with lower potential productivity. Almost all of the Region's acres classed as least productive, yielding less than 50 cubic feet per acre per year, are found here. Idaho's commercial forest land is generally more productive than that in other areas east of the Cascade Range.

Within the C-NP Region there is a wide range of commercial forest land capacities. The high productivity of the forest land in western Washington and western Oregon is shown by the large concentration of timber volume on relatively few acres. The Willamette subregion, for example, contains 16 percent of the Region's sawtimber volume on only 8 percent of the commercial forest area. In contrast, the Clark Fork-Kootenai-Spokane subregion accounts for only 11 percent of the timber volume even though it has 23 percent of the commercial forest area (table 3).

Table 2.—Commercial forest land area in the Columbia-North Pacific Region and the United States, by cubic-foot yield class, January 1, 1963

Yield class[1]	Columbia-North Pacific Region[2] [3]		United States[3]	
	Percent	*MM acres*	*Percent*	*MM acres*
120 cubic feet or more	26	19	8	44
85–120 cubic feet	18	13	23	116
50–85 cubic feet	35	25	46	233
Less than 50 cubic feet	21	15	23	116
All classes	100	72	100	509

[1] A classification of forest land based on mean annual increment culmination of fully stocked stands of species currently occupying the area. Yields may be substantially higher under intensive management.

[2] All of Washington, Oregon, Idaho, and western Montana, but does not include Wyoming.

[3] Source: Based on "Timber Trends in the United States" but adjusted for January 1, 1968, data for Idaho and western Montana.

Table 3.—Area of commercial forest land and volume of sawtimber in the Columbia-North Pacific Region, by subregion, January 1, 1966

Subregion	Commercial forest land		Volume[1]		Average volume per acre
	M acres	*Percent*	*MM bd. ft.*	*Percent*	*Bd. ft.*
Clark Fork-Kootenai-Spokane	15,737	23	115,802	11	7,359
Upper Columbia	4,881	7	37,266	3	7,635
Yakima	1,645	2	29,168	3	17,731
Upper Snake	2,225	3	15,684	2	7,049
Central Snake	3,677	5	34,498	3	9,382
Lower Snake	8,881	13	74,557	7	8,395
Mid-Columbia	5,908	8	61,964	6	10,488
Lower Columbia	3,535	5	96,571	9	27,319
Willamette	5,895	8	168,542	16	28,591
Coastal	10,213	15	260,365	25	25,493
Puget Sound	6,071	9	134,589	13	22,169
Oregon Closed Basin	1,580	2	16,709	2	10,575
Total	70,248	100	1,045,715	100	14,886

[1] International 1/4-inch rule.

In most areas of the Columbia-North Pacific Region, private forest ownerships have a substantial proportion of their lands in high site areas. For example, in the Douglas-fir region, 72 percent of forest industry's and 63 percent of other private owners' forest acres are in the highest capacity class. Nearly half of the private commercial forest land in Idaho and one quarter of that in the ponderosa pine region is capable of yielding at least 85 cubic feet per acre per year. By comparison, western Montana's private forest lands have generally low productive capacity (tables 21-24, pages 43-45).

The Columbia-North Pacific Region has one-third of the Nation's total timber

The Columbia-North Pacific Region contains an estimated net volume of 217 billion cubic feet of timber on commercial forest land in trees 5 inches and larger in diameter at breast height (d.b.h.) (table 30, page 54). This is nearly one-third of the Nation's total timber volume. Live, sound trees account for 97 percent of the Region's timber volume (210 billion cubic feet); the remaining 3 percent is in non-growing-stock material, including both sound and rotten cull trees and salvable dead trees. Eighty-one percent of the live, sound volume (171 billion cubic feet) is in sawtimber-size trees; and 19 percent, or 39 billion cubic feet, is in poletimber-size trees.

The estimate of sawtimber volume in Washington and Oregon includes trees 11.0 inches d.b.h. and larger. In Idaho and western Montana, trees are generally smaller, and smaller trees are more commonly utilized. As a consequence, the lower diameter for sawtimber trees is 9.0 inches d.b.h. The volume figures for sawtimber in this report include these two differing minimum standards.

The Columbia-North Pacific Region has 1 trillion board feet of sawtimber,[6] of which 97 percent is in softwood species and 3 percent in hardwoods (table 31, page 56). This Region has about 41 percent of the Nation's total sawtimber inventory and almost half of the Nation's softwood sawtimber volume.

Public owners account for 71 percent of the sawtimber volume, and the National Forests have over three-fourths of this (table 31). The remaining 29 percent of the total sawtimber inventory is in private ownership, with forest industries owning about two-thirds of it. The following tabulation shows the ownership of sawtimber in the Region:

Ownership class	Volume (MM bd. ft.)
National Forest	565,823
Other public	176,868
Total public	742,691
Private	303,024
Total, all owners	1,045,715

Four species groups make up 79 percent of the total sawtimber volume in the Region. These are Douglas-fir (44 percent), western hemlock (14 percent), the true firs (12 percent), and ponderosa and Jeffrey pines (9 percent) (table 31, page 56).

In the Columbia-North Pacific Region, about 41 percent of the sawtimber inventory is over 29 inches in diameter at breast height. The largest sawtimber is generally concentrated in western Oregon and western Washington, although the ponderosa pine region also has substantial volumes of large timber. Over the years, the average size of the sawtimber inventory has been declining with the continued harvest of the

[6] All board-foot volumes in this report, unless otherwise stated, are expressed in terms of the International 1/4-inch rule.

old growth. New manufacturing technology in both primary and secondary manufacturing has been developing as the harvest of small-size trees has been increasing. This trend toward smaller log utilization will continue and will tend to reduce the present differences in tree size across the Region. At present, a wide differential in size of trees still exists. For instance, the proportion of the number of trees under 20 inches d.b.h. ranges from 18 percent in western Oregon to 67 percent in western Montana.

Columbia-North Pacific Region produces 20 percent of Nation's sawtimber growth

In 1962, the net growth of the sawtimber in the Region amounted to 11.4 billion board feet, or 20 percent of the Nation's sawtimber growth (table 4). Western Washington accounted for 43 percent of the Columbia-North Pacific Region's net annual growth, reflecting the presence of thrifty second-growth stands, good site, and favorable stocking. The net growth in other areas is lower, partly due to poorer sites and partly to a greater proportion of old-growth stands. In all areas, forest management can increase timber yields through augmented investments in more intensive forest management practices.

Log production in the Columbia-North Pacific Region continues upward

In 1869, about 218 million board feet of logs were harvested in the Columbia-North Pacific Region. By 1899, 2.5 billion board feet of timber were harvested. Between 1899 and 1929, the Region's forest economy went through its greatest period of expansion, and the timber cut supporting the industrial capacity increased about 500 percent to 15 billion board feet. During the Great Depression, the Region's timber harvest declined with the drop in national demand, but during World War II production increased. In recent years, the timber harvest has continued to increase but at a slower rate. During the period 1952 through 1964, production increased from 18.4 to 21.0 billion board feet (table 5).

Table 4.—Net annual growth of growing stock and sawtimber on commercial forest land in the Columbia-North Pacific Region, by State area, 1962[1]

Area	Sawtimber		Growing stock	
	Total	Per acre	Total	Per acre
	Million board feet[2]	*Board feet*[2]	*Million cubic feet*	*Cubic feet*
Western Oregon	2,700	196	595	42
Western Washington	4,920	484	1,137	105
Eastern Oregon	955	84	279	25
Eastern Washington	997	119	304	36
Northern Idaho	707	108	169	26
Southern Idaho	505	70	114	15
Western Montana	647	62	160	15
Total	11,431	158[3]	2,758	38[3]

[1] Includes all of Washington, Oregon, Idaho, and western Montana and is based on data in "Timber Trends in the United States."
[2] International 1/4-inch rule.
[3] Weighted average.

Table 5.—Annual log production by subregion and by owner group in the Columbia-North Pacific Region in 1952, 1956, 1962, and 1964

(In thousand board feet, International 1/4-inch rule)

Subregion and owner group	1952	1956	1962	1964
1. Clark Fork-Kootenai-Spokane:				
National Forest	405,347	784,322	910,597	1,029,612
All other	777,289	1,050,227	791,968	852,404
Total	1,182,636	1,834,549	1,702,565	1,882,016
2. Upper Columbia:				
National Forest	101,555	132,607	231,541	253,006
All other	216,571	292,473	215,393	270,083
Total	318,126	425,080	446,934	523,089
3. Yakima:				
National Forest	49,648	53,607	128,721	137,602
All other	125,861	118,070	174,079	244,073
Total	175,509	171,677	302,800	381,675
4. Upper Snake:				
National Forest	15,403	38,551	36,844	59,694
All other	5,061	10,177	8,711	14,111
Total	20,464	48,728	45,555	73,905
5. Central Snake:				
National Forest	75,976	272,940	205,750	343,545
All other	146,379	113,784	106,843	139,245
Total	222,355	386,724	402,593	482,790
6. Lower Snake:				
National Forest	119,944	218,256	324,979	399,696
All other	623,762	837,486	610,100	605,951
Total	743,706	1,055,742	935,079	1,005,647
7. Mid-Columbia:				
National Forest	336,971	461,046	552,135	579,904
All other	561,999	680,496	403,611	421,281
Total	898,970	1,141,542	955,746	1,001,185

Table 5 continued on p. 12.

Table 5.—Annual log production by subregion and by owner group in the Columbia-North Pacific Region in 1952, 1956, 1962, and 1964 Continued

(In thousand board feet, International 1/4-inch rule)

Subregion and owner group	1952	1956	1962	1964
8. Lower Columbia:				
National Forest	191,913	305,250	589,084	564,394
All other	1,289,192	1,681,559	1,353,081	1,819,847
Total	1,481,105	1,986,809	1,933,165	2,384,241
9. Willamette:				
National Forest	669,523	843,934	1,553,650	1,519,130
All other	3,337,539	2,469,993	2,098,979	2,176,612
Total	4,007,062	3,313,927	3,652,629	3,695,742
10. Coastal:				
National Forest	526,856	690,524	1,150,271	1,421,363
All other	6,499,764	6,016,730	4,357,030	4,889,088
Total	7,026,620	6,707,254	5,507,301	6,411,451
11. Puget Sound:				
National Forest	446,470	458,177	656,004	848,402
All other	1,697,862	1,840,256	1,513,360	1,935,937
Total	2,144,332	2,298,433	2,169,364	2,784,339
12. Oregon Closed Basin:				
National Forest	96,514	125,832	153,652	231,120
All other	59,792	188,652	78,716	107,939
Total	156,306	314,484	232,368	339,059
Grand total:				
National Forest	3,036,120	4,385,046	7,574,228	7,387,568
All other	15,341,071	15,299,903	11,711,871	13,577,571
Total	18,377,191	19,684,949	18,286,099	20,965,139

THE PRESENT FOREST INDUSTRY

The lumber industry

Lumber is the Region's major forest product. Production of lumber increased greatly from the mid-1800's to 1929, declined with the Great Depression, and then recovered by the 1940's. Since 1950, lumber production has fluctuated between 12 and 15 billion board feet, and in 1965 nearly 15 billion board feet of lumber were produced by 925 sawmills (tables 6 and 7).

The Douglas-fir region is the leading lumber producing area in the Columbia-North Pacific Region, with about 8.6 billion board feet of production in 1966. Both lumber production and the number of sawmills have been declining in western Oregon and western Washington. Between 1950 and 1966, lumber production declined 14 percent, and during the 1956-64 period, the number of sawmills declined 38 percent in western Oregon and 37 percent in western Washington.

The inland sawmills, east of the Cascade Range, have been increasing their total lumber production. Their share of the C-NP Region's lumber production has increased from 25 percent in 1950 to 38 percent in 1965. Eastern Washington's lumber output has been growing more rapidly than most other areas in the Western United States; in 1950 eastern Washington had a lumber production of 668 million board feet, and by 1965 it had increased to 1.2 billion board feet. A recent study of eastern Washington showed that the number of sawmills has been declining there despite increasing lumber production (Wall et al. 1966). In 1953 there were 296 mills and by 1963 the number had dropped to only 77. It is estimated that in 1967 there were only 66 mills remaining in eastern Washington. In general, the smallest sawmills are the ones which have disappeared.

Between 1950 and 1962, lumber production increased 26 percent in eastern Oregon but the number of sawmills dropped from 70 to 30. In the business expansion period 1961 through 1967, the number of sawmills has increased from 30 to 50 mills and lumber production has been increasing.

In Idaho and western Montana, lumber production has been generally increasing since the early 1950's, and the number of sawmills has been declining. In 1956, Idaho had 311 sawmills in operation, and by 1962 there were only 193 mills remaining. In all of Montana, there were 333 mills operating in 1956, but only 209 remained in 1962 (Wilson 1964a and 1964b). Western Montana has had the greatest growth (up 122 percent) in lumber production in the Columbia-North Pacific Region during the 1950-62 period, and production in Idaho increased the smallest amount (17 percent).

The plywood industry

The Columbia-North Pacific Region has been the leading plywood supplier in the Nation since Douglas-fir plywood was first shown as a potential product at the Lewis and Clark Exposition in 1905. This industry developed in the Puget Sound subregion and was chiefly associated with door manufacturers in its early stages. New technology in making plywood aided in making better and more acceptable products, and after World War II, the industry grew rapidly, especially in western Oregon.

In 1940, the Columbia-North Pacific Region accounted for 100 percent of the softwood plywood production in the Nation, and in 1965 it accounted for about 87 percent of the Nation's plywood production (11 billion square feet, 3/8-inch basis) (table 6). The Coastal subregion of Washington and Oregon and the Willamette subregion together have about two-thirds

Table 6.--Total output of timber products, by product and by subregion and State, in the Columbia-North Pacific Region, 1965

Subregion and State	Lumber[1]	Plywood[2] (3/8-inch)	Woodpulp[3]	Particle-board (3/4-inch)[4]	Miscellaneous products[5]	Foreign log exports[6]
	M bd. ft.	*MM sq. ft.*	*Tons*	*MM sq. ft.*	*M cu. ft.*	*M cu. ft.*
1. Clark Fork-Kootenai-Spokane:						
Idaho	685,788	67	–	3	3,288[7]	–
Montana	1,254,070	465	270,000	–	3,004[7]	–
Washington	168,403	–	45,232	–	2,138	–
Total	2,108,261	532	315,232	3	8,430	–
2. Upper Columbia:						
Washington	531,116	–	16,507	–	6,740	500
3. Yakima:						
Washington	260,886	125	–	–	3,310	–
4. Upper Snake:						
Idaho	48,131	–	–	–	214	–
Wyoming	2,889	–	–	–	6	–
Total	51,020	–	–	–	220[7]	–
5. Central Snake:						
Idaho	306,286	51	–	–	2,158[7]	–
Oregon	69,560	18	–	–	189	–
Total	375,846	69	–	–	2,347	–
6. Lower Snake:						
Idaho	839,795	148	251,000	–	4,519[7]	–
Oregon	245,283	102	–	–	665	–
Washington	2,096	–	–	–	27	–
Total	1,087,174	250	251,000	–	5,211	–
7. Mid-Columbia:						
Oregon	1,052,479	144	53,948	17	3,366	–
Washington	219,499	69	165,070	–	2,785	–
Total	1,271,978	213	219,018	17	6,151	–
8. Lower Columbia:						
Oregon	329,832	156	132,523	–	2,056	–
Washington	949,994	642	1,517,003	3	14,833	12,250
Total	1,279,826	798	1,649,526	3	16,889	12,250
9. Willamette:						
Oregon	3,165,402	3,873	634,462	132	19,736	7,617
10. Coastal:						
Oregon	2,775,783	3,679	462,067	133	17,304	25,567
Washington	432,784	254	247,607	–	6,758	45,433
Total	3,208,567	3,933	709,674	133	24,062	71,000
11. Puget Sound:						
Washington	1,435,222	1,278	1,595,581	–	22,409	58,800
12. Oregon Closed Basin:						
Oregon	181,173	10	–	–	492	–
Grand total	14,956,471	11,081	5,391,000	288	115,997	150,167

[1] Based on "1964-65 Statistical Yearbook" by Western Wood Products Association (1966).
[2] Based on 1965 American Plywood Association softwood plywood data and forest industries hardwood plywood data.
[3] Estimates of woodpulp production based on preliminary wood consumption data for the West (U.S. Bureau of Census).
[4] Based on 1965 U.S. Census of Manufactures data.
[5] Pilings, poles, posts, fuelwood, ties, excelsior, shingles, bolts, etc.
[6] Based on 1965 U.S. Department of Commerce data.
[7] 1964 data (Intermountain Forest and Range Experiment Station).

of the Region's plywood capacity. In recent years, Idaho and western Montana's plywood industry has been growing relative to that in Washington and Oregon. The growth of the plywood industry in California and the Southern States has reduced the Columbia-North Pacific Region's share of national plywood production.

The pulp industry

The pulp and paper industry began in the early 1880's in Oregon and moved to Washington in 1885. The Washington State pulp industry grew most rapidly through the 1920's because it had the raw materials needed for sulfite pulping. As technology changed, use of a wider range of species became possible through the sulfate pulping process. Washington attracted even more pulp industry development; in 1965 this State ranked second in woodpulp production in the Nation. The major pulp industry growth in Oregon, Idaho, and western Montana has occurred since World War II, especially in the late 1950's and early 1960's. In 1947, the Region's pulp industry produced about 2 million tons of pulp, and in 1965 it produced approximately 5.4 million tons or 16 percent of the Nation's woodpulp (table 6).

In 1965, the Lower Columbia and the Puget Sound subregions together accounted for 60 percent (3.2 million tons) of the pulp production in the Columbia-North Pacific Region. The Coastal subregion and the Willamette subregions are also major pulp producers, with 709,674 tons and 634,462 tons of production, respectively. The Clark Fork-Kootenai-Spokane subregion and the Lower Snake subregion were the largest pulp producers on the east side of the Cascades with 315,232 tons and 251,000 tons of production, respectively, in 1965. Due to favorable raw material and water supply factors, the subregions in eastern Washington, Idaho, and western Montana offer some of the best chances for new pulpmill installations in the coming decades.

The expansion of the pulping activity in the Region has been based in part on the availability of wood residues from other manufacturing processes. In 1950, roundwood accounted for 81 percent of the total wood fiber consumption by the Region's pulpmills. By 1965, however, it was estimated that 68 percent of all the wood fiber consumed was residue from sawmills, planing mills, and plywood plants. Further expansion based on available residue supplies appears to be limited in view of the near-term increasing export of chips to Japan and the long-term leveling off of mill residue production.

The particleboard industry

During the 1950's, the particleboard industry was established, based on available supplies of sawmill residues. For this reason, the industry located mostly in Oregon near large raw material supplies. In 1965, only about 51 percent of the installed particleboard capacity was used to produce 288 million square feet (3/4-inch) of particleboard (table 6).

Foreign log exports

The 1960's have been marked by a rapid rise in foreign demand for roundwood from the Columbia-North Pacific Region. In 1961, 56 million cubic feet of timber were exported from the Region, and by 1965, log exports had increased 2.7 times to 150 million cubic feet. Since 1965, the export of roundwood from the Region has continued to climb, reaching 171 million cubic feet in 1966 and 262 million cubic feet in 1967. Japan purchases most of this Region's exported roundwood, although its share of the total Region's exports has varied over time. In 1961, it took 98 percent of the total volume exported. In 1965, this decreased to 80 percent, with Canada increasing its share from 2 percent to 13 percent. In 1967, Japan (95 percent), Canada (3 percent), and South Korea (2

Table 7.—Number of plants and plant capacity, by manufacturing process,

Subregion and State	Sawmills[1]		Veneer only[1]	
	Number of plants	Daily capacity	Number of plants	Annual capacity (1/8-inch basis)
		Bd. ft.		*Million sq. ft.*
1. Clark Fork-Kootenai-Spokane:				
Idaho	70	3,024,830	–	–
Montana	126	5,242,050	–	–
Washington	11	821,000	–	–
Total	207	9,087,880	–	–
2. Upper Columbia:				
Washington	48	2,218,500	–	–
3. Yakima:				
Washington	9	922,000	1	9
4. Upper Snake:				
Idaho	31	387,630	–	–
Wyoming	1	25,000	–	–
Total	32	412,630	–	–
5. Central Snake:				
Idaho	26	1,272,760	–	–
Oregon	5	215,000	–	–
Total	31	1,487,760	–	–
6. Lower Snake:				
Idaho	57	3,601,090	–	–
Oregon	9	705,000	–	–
Washington	1	35,000	–	–
Total	67	4,341,090	–	–
7. Mid-Columbia:				
Oregon	32	3,715,000	2	77
Washington	10	373,000	–	–
Total	42	4,452,000	2	77
8. Lower Columbia:				
Oregon	9	1,420,000	–	–
Washington	42	3,450,000	6	688
Total	51	4,870,000	6	688
9. Willamette:				
Oregon	185	12,265,000	21	3,247
10. Coastal:				
Oregon	122	11,058,000	11	2,078
Washington	16	1,335,500	1	175
Total	138	12,393,500	12	2,253
11. Puget Sound:				
Washington	110	6,260,000	3	521
12. Oregon Closed Basin:				
Oregon	5	655,000	–	–
Grand total	925	59,365,360	45	6,795

[1] "Directory of Forest Products Industry" (Anonymous 1966).
[2] "Directory of the Forest Products Industry" (Anonymous 1967).

in the Columbia-North Pacific Region, by subregion and State, 1965

Particleboard[2] [3]		Plywood[1] [3]		Woodpulp[4]	
Number of plants	Annual capacity (3/4-inch basis)	Number of plants	Annual Capacity (3/8-inch basis)	Number of plants	Daily capacity
	Million sq. ft.		*Million sq. ft.*		*Tons*
1	8	1	72	–	–
–	–	6	510	1	700
–	–	–	–	1	137
1	8	7	582	2	837
–	–	–	–	1	50
–	–	1	132	–	–
–		–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
–	–	[1][2]	48	–	–
–	–	1	18	–	–
–	–	2	66		
–	–	[1][2]	140	1	650
–	–	1	108	–	–
–	–	–	–	–	–
–	–	2	248	1	650
1	33	2	146	2	230
–	–	1	70	1	500
1	33	3	216	3	730
–	–	2	153	2	565
1	7	7	691	5	4,595
1	7	9	844	7	5,160
6	257	41	3,897	11	2,705
5	260	39	3,724	5	2,970
–	–	6	351	2	750
5	260	45	4,075	7	2,720
–	–	20	1,416	14	4,833
–	–	1	80	–	–
14	565	131	11,556	46	17,685

[3] Plants under construction are not included.
[4] "Lockwood's Directory of Paper and Allied Trades, 1966" (Lockwood Trade Journal Co., Inc. 1966).

percent) were the major importers of the Region's roundwood (Hamilton 1968).

In 1965, the Coastal subregion of western Oregon and western Washington ranked first in foreign log exports with a total of 71 million cubic feet. The Puget Sound subregion exported the second largest roundwood volume to foreign countries – 59 million cubic feet. These exported volumes were not necessarily harvested in the subregions mentioned above.

In 1968, Congress passed a law limiting the foreign export of logs from Federal lands. The law came into being after the projections were made for this study; however, it is expected that the projections will not be significantly affected.

Forest industry employment has been declining

There has been a long-term downward trend in total forest industry employment due, in part, to increases in productivity. But this influence, which reduces employment, has been somewhat offset by changes in industry mix and the increase in further manufacturing. Employment in logging, sawmills, and planing mills has been declining since 1950 and that in miscellaneous wood manufacturing has been relatively stable. Employment in plywood plants and the pulp, paper, and allied products industry has been increasing over the past 15 years. In 1950, about 169,000 workers were employed by the forest industries of the Columbia-North Pacific Region, and in 1965, the employment level was nearly 3 percent lower at 165,789 workers. Because of the excellent business conditions in 1965 and the intensive use of plant capacity, employment levels in that year were above the long-term average.

In 1965, the State of Oregon, exclusive of Klamath County, had the largest forest industry employment in the Columbia-North Pacific Region (78,765), Washington was second (66,724), and Idaho was third (12,385). The Willamette subregion had the largest forest industry employment of any subregion – 39,944. The Coastal subregion ranked second with 35,913 workers, and the Puget Sound subregion ranked third with 31,360 workers (table 8).

Although the manufacture of lumber provides the most employment for the Region as a whole, it leads the other major forest industries in only Idaho and western Montana. Here, employment in sawmills and planing mills (SIC 242)[7] accounted for 7,719 and 4,740 employees, respectively, in 1965. In Washington, the pulp, paper, and allied products industry (SIC 26) was the leading employer with 19,789 workers. Sawmills and planing mills (SIC 2421) in Washington ranked second with 16,421 workers, whereas veneer and plywood plants (SIC 2432) ranked third with 10,480 workers. In all of Oregon, including Klamath County, the veneer and plywood industry (SIC 2432) was the largest single forest industry employer with 27,629 workers in 1965. Sawmills and planing mills (SIC 2421) ranked second with 25,510 employees.

The employment data are based on statistics compiled by the respective State employment agencies. Employment totals presented in the detailed table may differ slightly from official figures because, when disclosure of covered employment for individual mills was a possibility, estimates of employment were developed based on average data for the industry.

[7]Standard Industrial Classification.

Table 8.—Forest industry employment in the Columbia-North Pacific Region by industry, and by subregion and State, 1965

(Number of persons)

Subregion and State	Logging (SIC 241)	Sawmills and planing mills (SIC 242)	Veneer, millwork, plywood, prefabricated structures (SIC 243)	All other (SIC 24)	Total (SIC 24)	Paper and allied products (SIC 26)	Total (All)
1. Clark Fork-Kootenai-Spokane:							
Idaho	843	2,434	299	259	3,835	–	3,835
Montana	1,488	4,740	1,296	91	7,615	300[1]	7,915
Washington	115	962	499	104	1,680	450[1]	2,130
Total	2,446	8,136	2,094	454	13,130	750	13,880
2. Upper Columbia:							
Washington	716	2,043	29	17	2,805	83[1]	2,888
3. Yakima:							
Washington	402	1,039	298	60	1,799	168	1,967
4. Upper Snake:							
Idaho	73	203	34	(2)	310	70[1]	380
Wyoming	(2)	–	–	–	(2)	–	–
Total	73	203	34	(2)	310	70	380
5. Central Snake:							
Idaho	342	1,615	494	33	2,484	–	2,484
Oregon	37	334	185	–	556	–	556
Total	379	1,949	679	33	3,040		3,040
6. Lower Snake:							
Idaho	1,316	3,467	7	96	4,886	800[1]	5,686
Oregon	297	688	231	–	1,216	–	1,216
Washington	21	47	–	–	68	–	68
Total	1,634	4,202	238	96	6,170	800	6,970
7. Mid-Columbia:							
Oregon	985	3,364	1,354	240	5,943	230[1]	6,173
Washington	384	731	193	–	1,308	430[1]	1,738
Total	1,369	4,095	1,547	240	7,251	660	7,911

See footnotes at end of table, p. 20.

Table 8.—Forest industry employment in the Columbia-North Pacific Region by industry, and by subregion and State, 1965—Continued

(Number of persons)

Subregion and State	Logging (SIC 241)	Sawmills and planing mills (SIC 242)	Veneer, millwork, plywood, prefabricated structures (SIC 243)	All other (SIC 24)	Total (SIC 24)	Paper and allied products (SIC 26)	Total (All)
8. Lower Columbia:							
Oregon	190	612	433	(2)	1,235	908	2,143
Washington	3,560	4,210	2,863	(2)	10,633	7,555	18,188
Total	3,750	4,822	3,296	(2)	11,868	8,463	20,331
9. Willamette:							
Oregon	5,626	9,866	17,140	1,933	34,565	5,379	39,944
10. Coastal:							
Oregon	5,847	7,915	12,771	(2)	26,533	995	27,528
Washington	2,909	2,454	1,764	(2)	7,127	1,258	8,385
Total	8,756	10,369	14,535	(2)	33,660	2,253	35,913
11. Puget Sound:							
Washington	4,501	7,484	8,645	885	21,515	9,845	31,360
12. Oregon Closed Basin:							
Oregon	82	1,092	31	(2)	1,205	–	1,205
State totals:							
Idaho	2,574	7,719	1,222	(2)	11,515	870[4]	12,385[4]
Montana	1,488	4,740	1,387	(2)	7,615	300	7,915
Oregon	13,064	23,871	34,318	(2)	71,253	7,512	78,765
Washington	12,608	18,970	15,357	(2)	46,935	19,789	66,724
Wyoming	(3)	–	–	–	(2)	–	(2)
Grand total	29,734	55,300	52,284	(2)	137,318	28,471[4]	165,789[4]

[1] Estimated to avoid disclosing figures for individual companies.
[2] Data for "All other, SIC 24" have been combined with "SIC 243" to avoid disclosure of figures for individual companies.
[3] Negligible.
[4] Totals differ from the official State totals because of modifications made in the data for several subregions to avoid disclosing figures for individual companies.

THE FUTURE FOREST ECONOMY, 1965-2020

The forest economy of the Columbia-North Pacific Region has been projected in terms of wood consumption, employment, and payrolls for the 1965-2020 period. The basic wood consumption projections were made first on a regional and half-State basis; then they were allocated to subregions on the basis of existing industry distribution. However, in some cases, such as in the pulp, paper, and allied products industry, allowance was made for new plant investment at new industrial sites in the various subregions.

The timber economy of the Columbia-North Pacific Region has been changing in several ways which differ from those foreseen several years ago in studies such as "Timber Trends in the United States" (U.S.D.A. Forest Service 1965) and "Prospective Economic Developments Based on the Timber Resources of the Pacific Northwest" (Gedney et al. 1966). For example, the demand for logs for foreign exports is much greater; eastern Oregon's projected increase in consumption of wood has not materialized; southern plywood production has captured more of the Nation's plywood market than projected; production of veneer and plywood has turned downward in western Oregon and western Washington although this industry's output has increased more in the inland portion of the Region than was projected; and public agencies have raised their annual allowable cuts in many areas of the Region. The increasing demand for all forest resources has been rapidly changing the outlook for both public and private owners concerning their timber production alternatives. Thus, for this study of the Columbia-North Pacific Region, a new look has been taken at the timber economy. As a result, the new projections of wood consumption by the forest industries differ from earlier studies such as the Willamette River Basin Report and the Puget Sound Basin and Adjacent Waters Report.[8]

[8]See footnote 2.

Future national demand for wood products to increase

The principal markets for forest products in the Columbia-North Pacific Region are distributed over the whole Nation. It is assumed that the future production of the forest industries of the Pacific Northwest will be strongly influenced by national demand. Also, the increasing worldwide demand for wood products, especially from the Pacific Rim countries, will continue to exert strong pressure to divert raw materials produced in the Pacific Northwest away from the Nation's marketplace. As a result, more wood will be demanded in future time periods.

National trends in quantities of wood products which will be demanded have been projected in the U.S.D.A. Forest Service report (1965). The projections were based on five major factors: population, household formation, gross national product, disposable personal income, and construction activity.

Total demand for lumber in the United States is projected to increase 22 percent between 1962 and 1985, even though lumber demand per capita is expected to decline. Plywood and veneer demand should double by 1985, with the South expected to supply an increasing share of the future market. Paper and board demand per capita should continue to increase so that total demand will continue to rise throughout the projection period at historic rates. The projections indicate that the demand for minor industrial products will remain about the same, but consumption of fuelwood is expected to decline. Although the domestic forests are expected to meet most of the increase in the Nation's future demand, imports of lumber, veneer logs, and pulpwood are nevertheless expected to increase.

The timber supply situation in the Columbia-North Pacific Region

The timber supply situation has been studied for each State. The relationship of the forest economy to the physical timber supply is complex, for it involves not only timber demands but the goals of the various forest-land owners. Consideration has been given to trends in log production, land use, forest growth, forest mortality, forest inventory, forest ownership, and anticipated owner goals in projections of the available timber supplies for the future. Many of these timber supply relationships have been derived from earlier studies made by the Pacific Northwest Forest and Range Experiment Station staff. Some of the projected timber supply data have been prepared especially for this study. The Intermountain Forest and Range Experiment Station in Ogden, Utah, has aided in preparing both present forest resource data and estimates of the future timber cut, growth, mortality, and forest inventory relationships for the States of Idaho, Montana, and Wyoming.

Projecting the acreage available for future timber production posed complex problems in this study. It was generally assumed that the present trends in forest land loss will continue in the C-NP Region. It was also assumed that the private forest land adjacent to Puget Sound would not have commercial harvests after 1985. On the other hand, it was assumed that logging technology will continue to improve, allowing timber harvests on forest land in the Region which cannot be logged by today's standards due to soil instability or steepness. These lands are classed as commercial forest lands in this study because they are capable of producing adequate timber yields.

Western Oregon timber cut to decline slightly

Even though western Oregon has a large part of the Nation's best forest-growing land, the future timber harvest in western Oregon will not be adequate to maintain the present level of wood consumption if present downward trends in private production continue and if present allowable cuts on the public lands are adhered to. This situation reflects the history of heavy cutting on private lands, leaving inventories of sawtimber at a low level, thus limiting the economically available supply of private timber. As evidence of this, log production from private lands has a distinct downward trend, even though prices for stumpage have been increasing.

It is assumed for the Columbia-North Pacific study that this trend toward lower private production will continue until cut and net growth come more into balance. The tendency toward higher stumpage prices and the expectation of increasing future demand for wood is assumed to be a motivating force in attracting a moderate level of continued reinvestment in private forestry, bringing these lands into a sustained level of physical production. This level will be much lower than the private timber harvest in 1965.

The public agencies in the Douglas-fir region are now evaluating alternatives in managing their own respective forest resources. They are considering their forest production alternatives in relation to projected private timber production and are studying the effect on the economy of alternative courses of cutting action. On the basis of these studies, future policy regarding timber harvests will be formulated.

It has been assumed for this study that the public agencies in western Oregon will increase their timber harvests above the 1965 levels as private production declines. The public effort will nearly stabilize the total flow of roundwood during most of

the 1970-2020 projection period at a point somewhat below the 1965 harvest. As a result of this assumption, the level of economic activity projected for western Oregon may be regarded as a high projection for it implies rather large investments by the public in forestry activities.

Western Washington timber harvest to increase

In western Washington, the period of heavy private cutting came earlier than in western Oregon. Lumbermen began cutting the private lands in the mid-1800's, and the private harvest reached its peak in the 1920's. Because this is an easily reforested area, most of the private lands regenerated quickly and now have a young, fast-growing inventory. In addition, substantial areas of old growth remain which are still being harvested. The harvest on private lands is once again moving upward stimulated by increasingly higher stumpage prices, new logging technology, and increased market acceptability of smaller timber. An increase in the harvest is projected to continue in the 1965-2020 period.

Public owners have been increasing their allowable cuts in the State of Washington. The Department of Natural Resources recently evaluated the potential of their lands and greatly raised their planned harvests based on new inventory data and an accelerated thinning program. The Bureau of Indian Affairs has accelerated the Indian timber harvests for about a 15-year period in western Washington. The Forest Service has been increasing the allowable cut, and it has been assumed for this study that further increases will take place.

Eastern Oregon harvest to increase

The production of logs in eastern Oregon has been increasing since the 1940's with most of the increase coming from the National Forests. During the past decade, the harvest from private lands has decreased.

Eastern Oregon is expected to have an increasing demand for raw materials as timber supplies become limited west of the Cascade Range. The prices for east-side timber should rise, and as a result, private land owners will eventually increase their log production. The projected increase in timber consumption in eastern Oregon is based on data in the reports of Gedney et al. (1966) and Gedney (1963).

Eastern Washington harvest to increase

Eastern Washington's forest economy has been generally growing since 1932, with more rapid growth in recent years. As in eastern Oregon, the public agencies have been supplying the increased raw material used in the past decade, with private log production data showing a slight downward trend.

Log production from public lands is projected to increase in eastern Washington during the 1965-2020 period. The projected growth of eastern Washington's forest industries will stimulate an increase in private log production. Because of the favorable net growth relationships projected for private lands, it is expected that the inventory can sustain a much higher level of harvesting activity than in the past.

Idaho and western Montana timber cut to increase

The timber economy of the Idaho and western Montana area will continue to grow during the 1965-2020 projection period, if the demands for timber products in the Nation continue to rise as projected and new logging and wood processing technology enables manufacturers to hold costs at levels allowing them to compete in the Nation's marketplace.

Idaho and western Montana have a large but underutilized forest resource. For many years, the national demand for timber was met by available timber supplies in other areas of the country, and the lower quality timber of the Rocky Mountain area was not used. The increasing demand for timber products has resulted in a trend toward intensive use of all forest lands, including even the less productive segment of the commercial forest land. In the 1960's, the forest economy in Idaho and western Montana has begun to broaden and develop. It is anticipated that as industrial growth continues, more of the less productive and presently inaccessible commercial forest land in Idaho and western Montana will be included in the timber-producing base.

The production levels established for this area are based on the projections made in the U.S.D.A. Forest Service report (1965). The projections for private lands were changed to bring future levels of cut and net growth more in line in order to sustain a vigorous timber inventory. National Forests will account for the largest part of the increase in future timber harvests in Idaho and western Montana, and it is assumed that they will make the large investments in forestry required to produce these projected timber volumes.

Roundwood consumption by lumber and wood products industry to decline

In 1965, the lumber and wood products industry (SIC 24) and foreign log exports consumed 3.5 billion cubic feet of roundwood in the Columbia-North Pacific Region (table 9). During the 1965-2020 projection period, the roundwood consumption by this group of forest-based industries will decline 11 percent, whereas the roundwood consumption by the pulp and paper industry (SIC 26) will increase.

It has been assumed in these projections that when raw material is scarce, the forest industry which adds the most value to its wood input during the manufacturing process will be better able to outbid other wood users for the resource. For example, plywood plants and log exporters have increased their shares of total timber harvest at the expense of sawmills in the Douglas-fir region. In the projections in the Columbia-North Pacific Region, it was assumed, based on present trends, that the distribution of timber harvest among its various end uses will continue to change. The degree of change will vary by subregions, depending on the availability of timber supply.

Table 9. Roundwood consumption by the lumber and wood products industry in the Columbia-North Pacific Region by subregion and State, 1965, with projections to the year 2020[1]

(In million cubic feet)

Subregion and State	1965	1970	1980	1990	2000	2010	2020
1. Clark Fork-Kootenai-Spokane:							
Idaho	117	121	129	139	137	131	120
Montana	239	218	215	217	173	180	175
Washington	29	31	36	38	40	40	41
Total	385	370	380	394	350	351	336
2. Upper Columbia:							
Washington	92	105	125	135	143	144	150
3. Yakima:							
Washington	54	62	75	83	91	95	100
4. Upper Snake:							
Idaho	7	7	8	8	8	8	7
Wyoming	–	–	–	–	–	–	–
Total	7	7	8	8	8	8	7
5. Central Snake:							
Idaho	55	58	62	67	67	65	61
Oregon	12	12	13	14	15	15	15
Total	67	70	75	81	82	80	76
6. Lower Snake:							
Idaho	149	159	171	185	185	180	169
Oregon	46	50	56	60	63	65	66
Washington	([2])	([2])	1	1	1	1	1
Total	195	209	228	246	249	246	236
7. Mid-Columbia:							
Oregon	176	172	179	181	186	189	193
Washington	43	49	60	65	69	71	76
Total	219	221	239	246	255	260	269
8. Lower Columbia:							
Oregon	66	50	42	39	40	40	43
Washington	228	214	229	219	241	243	216
Total	294	264	271	258	281	283	259
9. Willamette:							
Oregon	836	654	580	555	575	574	606
10. Coastal:							
Oregon	775	624	559	538	548	540	564
Washington	141	175	196	179	159	140	106
Total	916	799	755	717	707	680	670
11. Puget Sound:							
Washington	406	427	472	450	457	445	385
12. Oregon Closed Basin:							
Oregon	28	28	29	29	29	29	30
State totals:							
Idaho	328	345	370	399	397	384	357
Montana	239	218	215	217	173	180	175
Oregon	1,939	1,590	1,458	1,416	1,456	1,452	1,517
Washington	993	1,063	1,194	1,170	1,201	1,179	1,075
Wyoming	–	–	–	–	–	–	–
Grand total	3,499	3,216	3,237	3,202	3,227	3,195	3,124

[1] Includes foreign log exports.
[2] Less than 500,000 cubic feet.

Saw-log consumption to decline 29 percent by 2020

In 1965, sawmills consumed 2.3 billion cubic feet of roundwood. By the year 2020, saw-log consumption in the Columbia-North Pacific Region is projected to decline 29 percent to 1.7 billion cubic feet (table 10). This decline takes place despite the projected increase in national demand. The downward projection in the C-NP Region reflects the assumption that many of the lumber industry's historical problems will continue into the future. The lumber industry is highly competitive; there are good substitutes for lumber, and increased costs of doing business cannot easily be passed on to the consumer. In the Columbia-North Pacific Region, the costs of doing business in the lumber industry have risen, especially in the form of stumpage and labor costs. The price of the end product has been relatively stable tending to squeeze out the profits of the sawmill. In part, this may explain why so many sawmills have been going out of business in the Region. With the projected increased demands for other uses of stumpage by the plywood and the pulp industries, it is expected that the sawmill will be at a relative disadvantage in acquiring raw material, and as a result, its share of the Region's timber harvest will decline.

Veneer-log consumption to increase 40 percent by 2020

Veneer and plywood plants consumed 877 million cubic feet of roundwood in 1965 in the Columbia-North Pacific Region. The growth of the plywood industry reflects its favorable competitive position among building materials and the technological breakthroughs in peeling smaller and rougher logs economically. In the long run, it has been assumed that the plywood industry will continue to increase, although not at its historical rate. The total consumption of veneer logs is projected to increase 40 percent to 1.2 billion cubic feet during the 1965-2020 period (table 10).

Roundwood consumption for miscellaneous wood products to increase

The estimated trend level of roundwood consumption for miscellaneous products in 1965 was 128 million cubic feet. Miscellaneous products include such products as poles, pilings, posts, fuelwood, and shingles. This roundwood consumption is projected to increase by 48 million cubic feet to 176 million cubic feet in 2020 (table 10). It is likely that the mix of miscellaneous products will change by 2020, with increasing emphasis on manufacturing in future time periods.

Foreign log exports to increase to 1980, then decline

The quantities of timber demanded by foreign countries along the Pacific Rim are expected to increase during the early part of the projection period. Experience has shown that log exporters have been effective in purchasing their timber requirements from this Region. The export of roundwood is projected to increase 2.2 times to 337 million cubic feet between 1965 and 1980 with most of the increase coming during the 1960's (table 10). Log exports are expected to decline starting in 1980 because of the increasing demand for roundwood in the United States, the increasing availability of wood from countries such as the Soviet Union, and the increasing domestic production of roundwood in Japan (Crawford 1965). By 2020, log exports are projected to amount to 57 million cubic feet which is 38 percent of the 1965 volume.

Table 10.—Roundwood consumption by the lumber and wood products industry in the Columbia-North Pacific Region, by type of use, 1965, with projections to the year 2020[1]

(In million cubic feet)

Type of use	1965	1970	1980	1990	2000	2010	2020
Veneer logs	878	836	926	978	1,112	1,173	1,228
Saw logs	2,343	1,957	1,819	1,753	1,734	1,715	1,663
Miscellaneous wood products	128[2]	137	155	176	186	186	176
Foreign log exports	150	286	337	295	195	121	57
Total roundwood	3,499	3,216	3,237	3,202	3,227	3,195	3,124

[1] For detail by State areas, see tables 35 through 41 in Appendix of Tables.

[2] The 1965 figure for miscellaneous products is a long-term trend-level point. For this reason, it differs from the 1965 miscellaneous output figure shown in table 6.

Available mill wood residue to decline

In 1965, sawmills, planing mills, veneer plants, and plywood plants in the Region produced 8.2 million tons of coarse residue, 4 million tons of sawdust, and 2.8 million tons of shavings. Calculations of potential mill residue production have been made for the Columbia-North Pacific Region based on the projected output of lumber and veneer. Because the projected decline in lumber production will more than offset the increase in veneer production, the output of mill residue will also decline. Coarse residue production is projected to decline 11 percent to 7.3 million tons by 2020; sawdust production will drop 29 percent to 2.9 million tons; and shavings production will drop 30 percent to about 2 million tons (table 11).

Pulpwood consumption to increase 1.6 times by 2020

In 1965, an estimated 839 million cubic feet of pulpwood was consumed by pulpmills in the Columbia-North Pacific Region. It was estimated that 68 percent of this total wood fiber consumption (567 million cubic feet) was residue from the lumber and wood products industry.

By the year 2020, the total wood consumption by the pulp, paper, and allied products industry is projected to increase 1.6 times to 2.2 billion cubic feet (table 12). The decreasing availability of plant residues will result in an increasing part of pulpwood production coming from roundwood. It is projected that roundwood consumption by pulpmills will increase from 272 million cubic feet in 1965 to 1.4

Table 11.–Production of mill residue in the Columbia-North Pacific Region in 1965, with projections to the year 2020[1]

(In thousand tons)

Type of residue	1965	1970	1980	1990	2000	2010	2020
Coarse	8,186	7,110	6,954	6,905	7,180	7,275	7,295
Sawdust	4,065	3,407	3,166	3,052	3,015	2,974	2,899
Shavings	2,807	2,326	2,143	2,054	2,032	2,005	1,952

[1] Assumes no change in utilization of roundwood.

billion cubic feet in 2020. Roundwood will then account for 65 percent of the total pulpwood consumption rather than the present 32 percent.

Almost every subregion is assumed to share in the expansion of the pulp, paper, and allied products industry, but the Lower Columbia and Puget Sound subregions will remain the most important pulpwood-consuming areas in the Region, with 575 million cubic feet and 546 million cubic feet of wood consumption, respectively, in 2020.

Forest industry employment to decline

Projections of forest industry employment have been made for the 1965-2020 period for the Columbia-North Pacific Region. The historical relationship between employment and wood input was studied for the period 1950 to 1965 for the major forest industries in each broad region within each State, except for Idaho and western Montana where State data were generally combined. Regressions were developed for SIC 2411, logging; SIC 2421, sawmills and planing mills; SIC 2432, veneer and plywood; and SIC 26, pulp, paper, and allied products. The historic trend in the employment-consumption relationship was projected to 2020 for each forest industry. By use of this and the predicted wood consumption by industry, future forest-based employment was calculated for the various geographic areas of the Columbia-North Pacific Region. In this text and appendix tables, the employment projections have not been rounded so that data for small geographic areas can be added and reconciled with various regional totals. This is not meant to imply that the projections are accurate to the detail shown.

Log sizes are changing, worker productivity is increasing, log utilization is improving, and the work week has been getting shorter over time. These various factors are reflected in the trend of the employment-consumption relationship even though each individual factor influences employment differently. Thus, the method of projecting employment implicitly takes into account a number of factors which have been changing and assumes that the same trends will continue.

Total forest industry employment in the Columbia-North Pacific Region is projected to decline 37 percent during the 1965-2020

Table 12.—Wood consumption by the paper and allied products industry in the Columbia-North Pacific Region by subregion and State, 1965, with projections to the year 2020[1]

(In million cubic feet)

Subregion and State	1965	1970	1980	1990	2000	2010	2020
1. Clark Fork-Kootenai-Spokane:							
Idaho	–	–	–	–	–	–	–
Montana	52	84	107	130	185	192	200
Washington	7	8	8	9	9	10	12
Total	59	92	115	139	194	202	212
2. Upper Columbia:							
Washington	3	3	8	11	13	17	20
3. Yakima:							
Washington	–	–	–	–	–	–	–
4. Upper Snake:							
Idaho	–	–	–	–	12	24	35
Wyoming	–	–	–	–	–	–	–
Total	–	–	–	–	12	24	35
5. Central Snake:							
Idaho	–	–	14	36	37	48	75
Oregon	–	–	–	–	–	–	–
Total	–	–	14	36	37	48	75
6. Lower Snake:							
Idaho	48	57	58	65	66	74	75
Oregon	–	–	–	–	–	–	–
Washington	–	–	–	–	–	–	–
Total	48	57	58	65	66	74	75
7. Mid-Columbia:							
Oregon	11	15	22	40	48	51	51
Washington	27	29	29	30	33	33	38
Total	38	44	51	70	81	84	89
8. Lower Columbia:							
Oregon	20	30	42	51	54	55	56
Washington	229	242	326	442	475	508	519
Total	249	272	368	493	529	563	575
9. Willamette:							
Oregon	95	145	203	243	257	262	267
10. Coastal:							
Oregon	69	105	148	177	187	191	195
Washington	37	39	53	72	77	83	85
Total	106	144	201	249	264	274	280
11. Puget Sound:							
Washington	241	254	342	464	499	534	546
12. Oregon Closed Basin:							
Oregon	–	–	–	–	–	–	–
Grand total	839	1,011	1,360	1,770	1,952	2,082	2,174

[1] Includes hardboard industry data.

period to about 104,000 (table 13). This decline will be entirely the result of decreased employment in the lumber and wood products industry where increasing worker productivity coupled with a declining wood consumption is projected to reduce employment 46 percent during the 1965-2020 period. Total employment in the lumber and wood products industry is predicted to be 73,816 in 2020 compared with 137,318 in 1965.

Pulp, paper, and allied products employment is projected to increase 6 percent to 30,189 employees. This increase reflects the rapid growth which is anticipated for the industry.

Washington State will be leading in forest employment in 2020 with 46,932 workers; Oregon will drop to second and will have 44,012 employed in the forest industries in 2020. Idaho will have 8,657 forest industry employees in 2020, and western Montana will have 4,404 employees (tables 14 and 15).

Forest management employment to increase 1.7 times by 2020

In 1962, it was estimated that the number of persons employed in forest management in the C-NP Region amounted to 17,500. Forest management employment includes all workers both publicly or privately engaged in the protection and management of forest lands for the production of timber and related products. It also includes the time worked by part-time employees and forest owners converted to an equivalent full-time basis.[9]

The trend toward more intensive forest management on all forest lands in the Columbia-North Pacific Region will continue to the year 2020. More forest management personnel will be needed as the multiple uses of forest lands are stressed, and it is projected that forest management employment will increase 1.7 times to 46,600 persons by the year 2020 (table 16).

Forest related payrolls to increase greatly by 2020

In 1962, worker incomes in all forest related activities amounted to $945 million. Workers in the lumber and wood products industries received 73 percent of the total, those in pulp, paper, and allied products received 18 percent, and forest management employees received 9 percent of the total 1962 payroll in the forest economy.

Between 1962 and 2020, total payrolls in the forest economy are projected to increase 1.4 times to a total of about $2.3 billion (1962 dollars). Payrolls are assumed to increase commensurate with worker productivity. Payrolls in the lumber and wood products industries in 2020 will amount to 34 percent of the total or $765 million, whereas the pulp, paper, and allied products payroll will be $537 million or 23 percent. Forest management payrolls are projected to be $975 million in 2020 or 43 percent of the total (tables 17, 18, and 19).

[9] Based on a concept of forest management developed in "The Economic Importance of Timber in the United States" (Hair 1963).

Table 13.—Forest industry employment in the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020[1] [2]

(Number of persons)

Subregion and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
1. Clark Fork-Kootenai-Spokane:								
Lumber and wood products	24	13,130	12,008	12,362	9,807	8,261	7,667	7,143
Pulp and paper	26	750	856	922	917	1,140	1,153	1,161
Total		13,880	12,864	13,284	10,724	9,401	8,820	8,304
2. Upper Columbia:								
Lumber and wood products	24	2,805	3,098	3,003	2,702	2,469	2,214	2,055
Pulp and paper	26	83	88	83	80	76	75	79
Total		2,888	3,186	3,086	2,782	2,545	2,289	2,134
3. Yakima:								
Lumber and wood products	24	1,799	1,999	1,981	1,853	1,741	1,632	1,570
Pulp and paper	26	168	165	254	310	300	291	306
Total		1,967	2,164	2,235	2,163	2,041	1,923	1,876
4. Upper Snake:								
Lumber and wood products	24	310	320	297	276	240	219	200
Pulp and paper	26	70	86	76	71	227	355	454
Total		380	406	373	347	467	574	654
5. Central Snake:								
Lumber and wood products	24	3,040	3,304	3,167	2,982	2,707	2,529	2,374
Pulp and paper	26	—	—	222	513	479	570	822
Total		3,040	3,304	3,389	3,495	3,186	3,099	3,196
6. Lower Snake:								
Lumber and wood products	24	6,170	5,741	5,094	4,571	3,824	3,301	2,865
Pulp and paper	26	800	928	841	855	784	809	752
Total		6,970	6,669	5,935	5,426	4,608	4,110	3,617
7. Mid-Columbia:								
Lumber and wood products	24	7,251	6,714	6,072	5,499	5,081	4,712	4,427
Pulp and paper	26	660	865	884	1,122	1,142	1,088	1,022
Total		7,911	7,579	6,956	6,621	6,223	5,800	5,449
8. Lower Columbia:								
Lumber and wood products	24	11,868	9,774	8,560	7,406	7,012	6,167	5,694
Pulp and paper	26	8,463	8,430	9,224	10,350	9,578	8,962	8,172
Total		20,331	18,204	17,784	17,756	16,590	15,129	13,866
9. Willamette:								
Lumber and wood products	24	34,565	27,720	23,226	20,587	19,527	18,197	17,949
Pulp and paper	26	5,379	6,866	7,607	7,709	7,060	6,345	5,782
Total		39,944	34,586	30,833	28,296	26,587	24,542	23,731
10. Coastal:								
Lumber and wood products	24	33,660	27,119	22,770	19,918	18,686	16,966	16,505
Pulp and paper	26	2,253	2,505	2,756	2,959	2,728	2,510	2,288
Total		35,913	29,624	25,526	22,877	21,414	19,476	18,793
11. Puget Sound:								
Lumber and wood products	24	21,515	18,479	16,944	15,150	14,670	13,491	12,601
Pulp and paper	26	9,845	9,442	10,311	11,757	10,896	10,253	9,351
Total		31,360	27,921	27,255	26,907	25,566	23,744	21,952
12. Oregon Closed Basin:								
Lumber and wood products	24	1,205	1,027	804	662	564	490	433
Pulp and paper	26	—	—	—	—	—	—	—
Total		1,205	1,027	804	662	564	490	433
Total C-NP Region:								
Lumber and wood products	24	137,318	117,303	104,280	91,413	84,782	77,585	73,816
Pulp and paper	26	28,471	30,231	33,180	36,643	34,410	32,411	30,189
Total		165,789	147,534	137,460	128,056	119,192	109,996	104,005

[1] More detailed employment projections are shown in tables 41 through 47 in the appendix.
[2] Data have not been rounded so that summary totals will agree.

Table 14.—Employment in the lumber and wood products industries in the Columbia-North Pacific Region, by subregion and State, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and State	1965	1970	1980	1990	2000	2010	2020
1. Clark Fork-Kootenai-Spokane:							
Idaho	3,835	3,796	3,488	3,233	2,803	2,536	2,308
Montana	7,615	6,447	7,163	4,996	3,978	3,764	3,538
Washington	1,680	1,765	1,711	1,578	1,480	1,367	1,297
Total	13,130	12,008	12,362	9,807	8,261	7,667	7,143
2. Upper Columbia:							
Washington	2,805	3,098	3,003	2,702	2,469	2,214	2,055
3. Yakima:							
Washington	1,799	1,999	1,981	1,853	1,741	1,632	1,570
4. Upper Snake:							
Idaho	310	320	297	276	240	219	200
Wyoming	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Total	310	320	297	276	240	219	200
5. Central Snake:							
Idaho	2,484	2,760	2,648	2,519	2,284	2,149	2,031
Oregon	556	544	519	463	423	380	343
Total	3,040	3,304	3,167	2,982	2,707	2,529	2,374
6. Lower Snake:							
Idaho	4,886	4,510	3,946	3,541	2,880	2,448	2,090
Oregon	1,216	1,162	1,082	971	890	807	733
Washington	68	69	66	59	54	46	42
Total	6,170	5,741	5,094	4,571	3,824	3,301	2,865
7. Mid-Columbia:							
Oregon	5,943	5,270	4,641	4,170	3,837	3,553	3,319
Washington	1,308	1,444	1,431	1,329	1,244	1,159	1,108
Total	7,251	6,714	6,072	5,499	5,081	4,712	4,427
8. Lower Columbia:							
Oregon	1,235	874	665	555	505	453	447
Washington	10,633	8,900	7,895	6,851	6,507	5,714	5,247
Total	11,868	9,774	8,560	7,406	7,012	6,167	5,694
9. Willamette:							
Oregon	34,565	27,720	23,226	20,587	19,527	18,197	17,949
10. Coastal:							
Oregon	26,533	20,791	16,873	14,576	13,602	12,435	12,194
Washington	7,127	6,328	5,897	5,342	5,084	4,531	4,311
Total	33,660	27,119	22,770	19,918	18,686	16,966	16,505
11. Puget Sound:							
Washington	21,515	18,479	16,944	15,150	14,670	13,491	12,601
12. Oregon Closed Basin:							
Oregon	1,205	1,027	804	662	564	490	433
State total:							
Idaho	11,515	11,386	10,379	9,569	8,207	7,352	6,629
Montana	7,615	6,447	7,163	4,996	3,978	3,764	3,538
Oregon	71,253	57,388	47,810	41,984	39,348	36,315	35,418
Washington	46,935	42,082	38,928	34,864	33,249	30,154	28,231
Wyoming	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Grand total	137,318	117,303	104,280	91,413	84,782	77,585	73,816

[1] Data have not been rounded so that summary totals will agree.
[2] Negligible.

Table 15.—Employment in the pulp, paper, and allied products industries in the Columbia-North Pacific Region, by subregion and State, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and State	1965	1970	1980	1990	2000	2010	2020
1. Clark Fork-Kootenai-Spokane:							
Idaho	–	–	–	–	–	–	–
Montana	300[2]	428	571	619	852	873	866
Washington	450	428	351	298	288	280	295
Total	750	856	922	917	1,140	1,153	1,161
2. Upper Columbia:							
Washington	83[2]	88	83	80	76	75	79
3. Yakima:							
Washington	168	165	254	310	300	291	306
4. Upper Snake:							
Idaho	70[2]	86	76	71	227	355	454
Wyoming	–	–	–	–	–	–	–
Total	70	86	76	71	227	355	454
5. Central Snake:							
Idaho	–	–	222	513	479	570	822
Oregon	–	–	–	–	–	–	–
Total	–	–	222	513	479	570	822
6. Lower Snake:							
Idaho	800[2]	928	841	855	784	809	752
Oregon	–	–	–	–	–	–	–
Washington	–	–	–	–	–	–	–
Total	800[2]	928	841	855	784	809	752
7. Mid-Columbia:							
Oregon	230[2]	444	533	816	846	801	720
Washington	430	421	351	306	296	287	302
Total	660	865	884	1,122	1,142	1,088	1,022
8. Lower Columbia:							
Oregon	908	1,185	1,313	1,330	1,218	1,095	998
Washington	7,555	7,245	7,911	9,020	8,360	7,867	7,174
Total	8,463	8,430	9,224	10,350	9,578	8,962	8,172
9. Willamette:							
Oregon	5,379	6,866	7,607	7,709	7,060	6,345	5,782
10. Coastal:							
Oregon	995	1,299	1,439	1,458	1,336	1,200	1,094
Washington	1,258	1,206	1,317	1,501	1,392	1,310	1,194
Total	2,253	2,505	2,756	2,959	2,728	2,510	2,288
11. Puget Sound:							
Washington	9,845	9,442	10,311	11,757	10,896	10,253	9,351
12. Oregon Closed Basin:							
Oregon	–	–	–	–	–	–	–
State total:							
Idaho	870[3]	1,014	1,139	1,439	1,490	1,734	2,028
Montana	300	428	571	619	852	873	866
Oregon	7,512	9,794	10,892	11,313	10,460	9,441	8,594
Washington	19,789	18,995	20,578	23,272	21,608	20,363	18,701
Wyoming	–	–	–	–	–	–	–
Grand total	28,471	30,231	33,180	36,643	34,410	32,411	30,189

[1] Data have not been rounded so that summary totals will agree.

[2] Estimated to avoid disclosing figures for individual companies.

[3] Totals differ slightly from official State figures to avoid disclosing data for individual companies.

Table 16.—Employment in forest management in the Columbia-North Pacific Region, by subregion and the United States, 1962, with projections to years 1980, 2000, and 2020[1] [2]

(Number of persons)

Subregion	1962	1980	2000	2020
1. Clark Fork-Kootenai-Spokane	1,572	2,246	3,340	4,185
2. Upper Columbia	436	622	926	1,160
3. Yakima	318	455	677	848
4. Upper Snake	61	88	130	163
5. Central Snake	402	575	856	1,072
6. Lower Snake	840	1,200	1,786	2,237
7. Mid-Columbia	836	1,195	1,778	2,227
8. Lower Columbia	1,990	2,843	4,230	5,298
9. Willamette	3,085	4,404	6,558	8,216
10. Coastal	5,352	7,646	11,376	14,250
11. Puget Sound	2,324	3,321	4,940	6,189
12. Oregon Closed Basin	284	405	603	755
Total, Columbia-North Pacific	17,500	25,000	37,200	46,600
Total, United States	90,800	129,300	191,600	239,900

[1] Forest management is the protection and management for the production of timber and related products.
[2] Allocation of forest management employment to subregions was based on 1964 timber harvest relationships.

Table 17.–Income (payrolls) in the lumber and wood products industries in the Columbia-North Pacific Region, by subregion, 1962, with projections to years 1980, 2000, and 2020

(Thousand dollars)

Subregion	1962	1980	2000	2020
1. Clark Fork-Kootenai-Spokane	66,273	94,001	77,026	74,059
2. Upper Columbia	13,842	22,835	23,021	21,306
3. Yakima	8,876	15,064	16,233	16,278
4. Upper Snake	1,613	2,258	2,238	2,074
5. Central Snake	15,697	24,081	25,240	24,614
6. Lower Snake	31,818	38,735	35,655	29,704
7. Mid-Columbia	36,143	46,171	47,375	45,899
8. Lower Columbia	58,649	65,090	65,379	59,035
9. Willamette	172,685	176,611	182,070	186,095
10. Coastal	167,740	173,143	174,228	171,124
11. Puget Sound	106,196	128,842	136,783	130,647
12. Oregon Closed Basin	6,018	6,114	5,259	4,489
Total	685,550	792,945	790,507	765,324

Table 18.—Income (payrolls) in the pulp, paper, and allied products industries in the Columbia-North Pacific Region, by subregion, 1962, with projections to years 1980, 2000, and 2020

(Thousand dollars)

Subregion	1962	1980	2000	2020
1. Clark Fork-Kootenai-Spokane	4,061	9,338	15,981	20,662
2. Upper Columbia	536	841	1,065	1,405
3. Yakima	1,001	2,573	4,205	5,446
4. Upper Snake	452	769	3,182	8,080
5. Central Snake	–	2,248	6,715	14,629
6. Lower Snake	5,003	8,518	10,990	13,383
7. Mid-Columbia	4,003	8,953	16,009	18,189
8. Lower Columbia	50,764	93,421	134,264	145,437
9. Willamette	33,416	77,043	98,967	102,902
10. Coastal	13,693	27,913	38,241	40,720
11. Puget Sound	58,801	104,430	152,740	166,420
12. Oregon Closed Basin	–	–	–	–
Total	171,730	336,047	482,359	537,273

Table 19.—Income (payrolls) in forest management in the Columbia-North Pacific Region, by subregion and the United States, 1962, with projections to years 1980, 2000, and 2020[1] [2]

(Thousand dollars)

Subregion	1962	1980	2000	2020
1. Clark Fork-Kootenai-Spokane	7,858	17,502	42,655	87,582
2. Upper Columbia	2,179	4,853	11,828	24,285
3. Yakima	1,592	3,547	8,645	17,750
4. Upper Snake	306	682	1,662	3,414
5. Central Snake	2,012	4,483	10,925	22,432
6. Lower Snake	4,200	9,355	22,800	46,814
7. Mid-Columbia	4,182	9,316	22,705	46,619
8. Lower Columbia	9,949	22,160	54,008	110,892
9. Willamette	15,426	34,361	83,742	171,945
10. Coastal	26,758	59,601	145,255	298,247
11. Puget Sound	11,620	25,883	63,080	129,520
12. Oregon Closed Basin	1,418	3,157	7,695	15,800
Total Columbia-North Pacific	87,500	194,900	475,000	975,300
Total United States	454,000	1,010,600	2,456,900	5,045,700

[1] Forest management is the protection and management of forests for the production of timber and related products.
[2] Allocation of forest management employment and payrolls to subregions was based on 1964 timber harvest relationships.

CONCLUSION

The Columbia-North Pacific Region has a large timber resource and a large forest industry based on that resource. After more than a century, lumber is still the primary forest product of the Region. Manufacturing of pulp, paper, and allied products, veneer and plywood, and board products has been and will continue to be of increasing importance. With the Nation's population increasing and personal incomes rising, the demand for timber products will increase. However, limited timber supply will be a constraint on the growth of the timber economy in the Columbia-North Pacific Region.

The forest industry's period of most rapid growth in the Columbia-North Pacific Region can probably be regarded as past history. Although continued growth of the forest industry can be expected, it will be at a much slower rate. In those areas with major untapped timber supplies, the industry can be expected to grow faster than in the Region as a whole. Generally, this new expansion will occur in subregions east of the Cascade Range.

With the shift in the product mix and the leveling off of wood fiber consumption in the future, the characteristics of the industry will continue to change. There will be fewer lumber mills and plywood plants, but the average capacity per mill will increase. Because of the need for better utilization of wood in such a competitive wood market, firms will tend to continue their integration of wood processing facilities. The capital supply, the raw material supply, the technical skills required, and the long-range outlook required, suggest a continuing trend toward more mergers and consolidation of forest-land ownership. The forest industry labor force will be shifting from lumber manufacture to plywood manufacture, pulp and paper processing, and secondary manufacturing of wood products. Some labor will become surplus to the forest industries, but the growth of the whole economy envisioned in this study should create job opportunities for displaced forest industry workers in other areas of economic activity.

As markets continue to expand within the Columbia-North Pacific Region, new types of industry will be attracted, and the Region will become less dependent on its timber economy. However, due to the nature of the forest industries and their tendency to locate near raw material supplies, many smaller communities scattered throughout the Region will continue to be highly dependent on timber-based activities.

The projected population increase in the Region and the Nation will act as a constraint on timber supply. People need water, roads, power, industrial sites, recreation areas, and home sites; and forested land is frequently required to fulfill these needs. For example, when forests are taken out of production for roads, powerlines, and home sites, this in effect reduces the longrun potential supply of timber, and it is possible that consumers may have to pay higher prices for timber products in the future. Recreation use also removes some forest land from production. In this study, it was assumed that present trends in forest-land loss would continue in the Columbia-North Pacific Region and the projections of wood fiber consumption reflect this limitation.

Man is more and more concerned with his environment and how it is affected by industrial activity. Allowance was made for this concern in projections, and it has been assumed that technology of pollution abatement will advance sufficiently to allow the projections of consumption to be realized. Economic activity ought to make man better off; it is hoped that, in some measure, this study of the timber economy will contribute to that end.

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APPENDIX OF TABLES

Table 20.—Commercial forest land area in the Columbia-North Pacific Region, by yield class and area, January 1, 1963

Yield class[1]	Columbia-North Pacific Region									
	Douglas-fir region[2]		Ponderosa pine region[3]		Idaho[4]		Western Montana[4]		Average[5]	
	Percent	*MM acres*	*Percent*	*MM acres*	*Percent*	*MM acres*	*Percent*	*MM acres*	*Percent*	*MM acres*
120 cubic feet or more	61	16	3	1	16	2	2	([6])	26	19
85–120 cubic feet	19	5	15	3	25	4	13	1	18	13
50–85 cubic feet	15	4	58	11	36	6	42	4	35	25
Less than 50 cubic feet	5	1	24	5	23	4	43	5	21	15
All classes	100	26	100	20	100	16	100	10	100	72

[1] A classification in terms of capacity for cubic-foot mean annual growth per acre.
[2] West of Cascade Range in Oregon and Washington.
[3] East of Cascades in Oregon and Washington including Klamath County, Oregon.
[4] As of January 1, 1968.
[5] Does not include Wyoming.
[6] Less than 500,000 acres.

Table 21.—Percent of commercial forest land area in the Douglas-fir region, by yield class and owner class, January 1, 1963[1] [2]

Yield class[3]	National Forest	Other public	Forest industry	Farmer and miscellaneous private
120 cubic feet or more	45	66	72	63
85–120 cubic feet	24	16	16	17
50–85 cubic feet	23	14	9	16
Less than 50 cubic feet	8	4	3	4
Total	100	100	100	100

[1] From Gedney et al. (1966).
[2] West of the Cascade Range in Oregon and Washington.
[3] A classification in terms of capacity for cubic-foot mean annual growth per acre.

Table 22.–Percent of commercial forest land area in the ponderosa pine region, by yield class and owner class, January 1, 1963[1] [2]

Yield class[3]	National Forest	Other public	Forest industry	Farmer and miscellaneous private
120 cubic feet or more	2	8	5	3
85–120 cubic feet	10	18	18	22
50–85 cubic feet	64	52	57	49
Less than 50 cubic feet	24	22	20	26
Total	100	100	100	100

[1] From Gedney et al. (1966).
[2] East of the Cascade Range in Washington and Oregon.
[3] A classification in terms of capacity for cubic-foot mean annual growth per acre.

Table 23.—Percent of commercial forest land area in the State of Idaho, by yield class and owner class, January 1, 1968[1]

Yield class[2]	National Forest	Other public	Forest industry	Farmer and miscellaneous private
120 cubic feet or more	15	20	31	13
85–120 cubic feet	23	30	27	30
50-85 cubic feet	35	33	38	41
Less than 50 cubic feet	27	17	4	16
Total	100	100	100	100

Source: Intermountain Forest and Range Experiment Station.
[1] The entire State.
[2] A classification in terms of capacity for cubic-foot mean annual growth per acre.

Table 24.—Percent of commercial forest land area in western Montana, by yield class and owner class, January 1, 1968

Yield class[1]	National Forest	Other public	Forest industry	Farmer and miscellaneous private
120 cubic feet or more	2	—	3	1
85–120 cubic feet	16	4	14	6
50–85 cubic feet	39	48	47	46
Less than 50 cubic feet	43	48	36	47
Total	100	100	100	100

Source: Intermountain Forest and Range Experiment Station.
[1] A classification in terms of capacity for cubic-foot mean annual growth per acre.

Table 25.—Area by land class, subregion, and State in the Columbia-North Pacific Region, January 1, 1966

(In thousand acres)

Subregion and State	Total land area[1]	Forest land				Total nonforest land
		Total	Commercial	Productive reserved	Unproductive	
1. Clark Fork-Kootenai-Spokane:						
Idaho and Montana[2]	20,870	17,021	14,560	888	1,573	3,849
Washington	2,028	1,237	1,177	28	32	791
Total	22,898	18,258	15,737	916	1,605	4,640
2. Upper Columbia:						
Washington	14,638	5,922	4,881	228	813	8,716
3. Yakima:						
Washington	5,313	1,897	1,645	74	178	3,416
4. Upper Snake:						
Idaho and Wyoming[2]	19,417	3,528	2,225	324	979	15,889
5. Central Snake:						
Idaho	13,891	4,414	3,004	461	949	9,477
Oregon	8,303	840	673	5	162	7,463
Total	22,194	5,254	3,677	466	1,111	16,940
6. Lower Snake:						
Idaho	14,701	9,689	7,059	1,242	1,388	5,012
Oregon	3,311	1,923	1,657	80	186	1,388
Washington	2,246	182	165	([3])	17	2,064
Total	20,258	11,794	8,881	1,322	1,591	8,464
7. Mid-Columbia:						
Oregon	15,533	6,987	5,215	98	1,674	8,546
Washington	2,598	752	693	1	58	1,846
Total	18,131	7,739	5,908	99	1,732	10,392
8. Lower Columbia:						
Oregon	413	343	336	–	7	70
Washington	3,946	3,388	3,199	46	143	558
Total	4,359	3,731	3,535	46	150	628
9. Willamette:						
Oregon	8,432	6,201	5,895	186	120	2,231
10. Coastal:						
Oregon	10,019	9,026	8,593	65	368	993
Washington	1,815	1,671	1,620	15	36	144
Total	11,834	10,697	10,213	80	404	1,137
11. Puget Sound:						
Washington	10,096	7,921	6,071	849	1,001	2,175
12. Oregon Closed Basin:						
Oregon	11,776	2,120	1,580	13	527	9,656
Grand total	169,346	85,062	70,248	4,603	10,211	84,284

[1] Source: U.S. Bureau of Census.
[2] Individual State statistics not available.
[3] Less than 500 acres.

Table 26.—Area of commercial forest land, by forest type and ownership and by subregion and State in the Columbia-North Pacific Region, January 1, 1966

(In thousand acres.)[1]

Subregion and State	Total all types			Total softwood types			Total hardwood types			Nonstocked		
	All owners	Public	Private	All owners	Public	Private	All owners	Public	Private	All owners	Public	Private
1. Clark Fork-Kootenai-Spokane:												
Idaho and Montana[1]	14,560	10,227	4,333	14,441	10,211	4,230	119	16	103	—	(2)	—
Washington	1,177	560	617	1,100	535	565	13	5	8	64	20	44
Total	15,737	10,787	4,950	15,541	10,746	4,795	132	21	111	64	20	44
2. Upper Columbia:												
Washington	4,881	3,622	1,259	4,747	3,550	1,197	40	18	22	94	54	40
3. Yakima:												
Washington	1,645	1,208	437	1,631	1,200	431	8	5	3	6	3	3
4. Upper Snake:												
Idaho and Wyoming[1]	2,225	2,054	171	2,139	2,007	132	86	47	39	—	(2)	—
5. Central Snake:												
Idaho	3,004	2,644	360	2,993	2,638	355	11	6	5	—	(2)	—
Oregon	673	529	144	664	522	142	3	2	1	6	5	1
Total	3,677	3,173	504	3,657	3,160	497	14	8	6	6	5	1
6. Lower Snake:												
Idaho	7,059	5,966	1,093	7,053	5,962	1,091	6	4	2	(2)	—	—
Oregon	1,657	1,084	573	1,639	1,070	569	5	1	4	13	13	(3)
Washington	165	113	52	163	111	52	(3)	—	(3)	2	2	(3)
Total	8,881	7,163	1,718	8,855	7,143	1,712	11	5	6	15	15	(3)
7. Mid-Columbia:												
Oregon	5,215	4,005	1,210	5,079	3,916	1,163	39	15	24	97	74	23
Washington	693	256	437	681	251	430	2	—	2	10	5	5
Total	5,908	4,261	1,647	5,760	4,167	1,593	41	15	26	107	79	28
8. Lower Columbia:												
Oregon	336	19	317	235	11	224	101	8	93	—	—	—
Washington	3,199	1,412	1,787	2,571	1,274	1,297	532	100	432	96	38	58
Total	3,535	1,431	2,104	2,806	1,285	1,521	633	108	525	96	38	58
9. Willamette:												
Oregon	5,895	3,168	2,727	4,999	3,009	1,990	716	91	625	180	68	112
10. Coastal:												
Oregon	8,593	4,782	3,811	6,591	4,077	2,514	1,453	455	998	549	250	299
Washington	1,620	504	1,116	1,403	458	945	148	17	131	69	29	40
Total	10,213	5,286	4,927	7,994	4,535	3,459	1,601	472	1,129	618	279	339
11. Puget Sound:												
Washington	6,071	2,658	3,413	4,930	2,434	2,496	1,065	184	881	76	40	36
12. Oregon Closed Basin:												
Oregon	1,580	1,217	363	1,520	1,175	345	18	9	9	42	33	9
Grand total	70,248	46,028	24,220	64,579	44,411	20,168	4,365	983	3,382	1,304	634	670

[1] Individual State statistics not available.

[2] 1,088,000 acres of nonstocked commercial forest land are included in the forest type data for the States of Idaho Montana and Wyoming.

[3] Less than 500 acres.

Table 27.—Area of commercial forest land, by softwood forest type and ownership

(In

Subregion and State	Douglas-fir			Hemlock–Sitka spruce			Ponderosa pine		
	All owners	Public	Private	All owners	Public	Private	All owners	Public	Private
1. Clark Fork-Kootenai-Spokane:									
Idaho and Montana[1] [2]	3,906	2,546	1,360	243	171	72	1,960	961	999
Washington	437	253	184	41	36	5	233	44	189
Total	4,343	2,799	1,544	284	207	77	2,193	1,005	1,188
2. Upper Columbia:									
Washington	1,779	1,337	442	40	23	17	1,879	1,352	527
3. Yakima:									
Washington	344	242	102	28	13	15	860	611	249
4. Upper Snake:									
Idaho and Wyoming[1] [2]	1,035	932	103	–	–	–	2	1	1
5. Central Snake:									
Idaho[2]	1,134	1,076	58	–	–	–	947	707	240
Oregon	88	67	21	–	–	–	436	327	109
Total	1,222	1,143	79	–	–	–	1,383	1,034	349
6. Lower Snake:									
Idaho	2,400	2,067	333	1	1	–	599	384	215
Oregon	385	270	115	–	–	–	602	292	310
Washington	45	36	9	4	4	–	64	27	37
Total	2,830	2,373	457	5	5	–	1,265	703	562
7. Mid-Columbia:									
Oregon	867	636	231	36	36	–	2,562	1,803	759
Washington	216	92	124	6	6	(3)	377	96	281
Total	1,083	728	355	42	42	(3)	2,939	1,899	1,040
8. Lower Columbia:									
Oregon	220	11	209	15	–	15	–	–	–
Washington	1,705	758	947	554	246	308	3	3	–
Total	1,925	769	1,156	569	246	323	3	3	–
9. Willamette:									
Oregon	4,043	2,310	1,733	493	313	180	5	5	–
10. Coastal:									
Oregon	4,779	3,008	1,771	826	299	527	142	120	22
Washington	435	105	330	908	297	611	–	–	–
Total	5,214	3,113	2,101	1,734	596	1,138	142	120	22
11. Puget Sound:									
Washington	2,478	955	1,523	1,777	923	854	(3)	(3)	–
12. Oregon Closed Basin:									
Oregon	510	494	16	–	–	–	594	382	212
Grand total	26,806	17,195	9,611	4,972	2,368	2,604	11,265	7,115	4,150

[1] Separate data not available.

[2] 1,088,000 acres of nonstocked commercial forest land are included in the forest type data for the States of Idaho, Montana, and Wyoming.

[3] Less than 500 acres.

and by subregion and State in the Columbia-North Pacific Region, January 1, 1966

thousand acres)

White pine			Lodgepole pine			Larch			Fir–spruce			Other softwoods		
All owners	Public	Private	All owners	Public	Private	All owners	Public	Private	All owners	Public	Private	All owners	Public	Private
558	497	61	3,111	2,527	584	2,592	1,973	619	1,728	1,373	355	343	163	180
72	61	11	188	60	128	67	37	30	62	44	18	–	–	
630	558	72	3,299	2,587	712	2,659	2,010	649	1,790	1,417	373	343	163	180
24	22	2	438	370	68	293	211	82	294	235	59	–	–	–
14	9	5	74	65	9	86	72	14	225	188	37	–	–	–
–	–	–	783	758	25	–	–	–	309	306	3	10	10	(2)
–	–	–	240	235	5	7	7	–	647	595	52	18	18	–
–	–	–	39	37	2	42	37	5	59	54	5	–	–	–
–	–	–	279	272	7	49	44	5	706	649	57	18	18	–
253	219	34	1,484	1,440	44	179	119	60	1,821	1,503	318	316	229	87
3	3	(3)	161	134	27	169	133	36	319	238	81	–	–	–
–	–	–	7	7	–	10	10	(3)	33	27	6	–	–	–
256	222	34	1,652	1,581	71	358	262	96	2,173	1,768	405	316	229	87
3	3	–	614	574	40	191	171	20	762	679	83	44	14	30
–	–	–	7	5	2	14	12	2	61	40	21	–	–	–
3	3	–	621	579	42	205	183	22	823	719	104	44	14	30
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
15	15	–	15	15	–	–	–	–	279	237	42	–	–	–
15	15	–	15	15	–	–	–	–	279	237	42	–	–	–
16	16	–	43	34	9	1	1	–	398	330	68	–	–	–
181	173	8	96	76	20	–	–	–	557	398	159	10	3	7
6	5	1	10	7	3	–	–	–	44	44	–	–	–	–
187	178	9	106	83	23	–	–	–	601	442	159	10	3	7
5	4	1	18	10	8	–	–	–	652	542	110	–	–	–
7	7	–	188	134	54	–	–	–	202	139	63	19	19	–
1,157	1,034	123	7,516	6,488	1,028	3,651	2,783	868	8,452	6,972	1,480	760	456	304

Table 28.—Area of commercial forest land, by ownership, subregion, and State in the Columbia-North Pacific Region, January 1, 1966

(In thousand acres)

Subregion and State	All ownerships	Federal					State, county, and municipal	Private
		Total	National Forest	Bureau of Land Management	Indian	Miscellaneous		
1. Clark Fork-Kootenai-Spokane:								
Idaho and Montana[1]	14,560	9,433	8,803	254	373	3	794	4,333[2]
Washington	1,177	496	486	–	–	10	64	617
Total	15,737	9,929	9,289	254	373	13	858	4,950
2. Upper Columbia:								
Washington	4,881	3,217	2,062	193	957	5	405	1,259
3. Yakima:								
Washington	1,645	1,082	622	5	455	(4)	126	437
4. Upper Snake:								
Idaho and Wyoming[1]	2,225	2,014	1,957	47	10	–	40	171
5. Central Snake:								
Idaho	3,004	2,465	2,423	42	–	–	179	360[3]
Oregon	673	528	504	24	–	–	1	144
Total	3,677	2,993	2,927	66	–	–	180	504
6. Lower Snake:								
Idaho	7,059	5,627	5,414	186	20	7	339	1,093
Oregon	1,657	1,076	1,065	9	2	–	8	573
Washington	165	110	109	1	–	–	3	52
Total	8,881	6,813	6,588	196	22	7	350	1,718
7. Mid-Columbia:								
Oregon	5,215	3,964	3,550	91	323	–	41	1,210
Washington	693	178	128	9	41	–	78	437
Total	5,908	4,142	3,678	100	364	–	119	1,647
8. Lower Columbia:								
Oregon	336	12	–	12	–	–	7	317
Washington	3,199	1,071	1,065	2	1	3	341	1,787
Total	3,535	1,083	1,065	14	1	3	348	2,104
9. Willamette:								
Oregon	5,895	2,971	2,382	589	–	–	197	2,727
10. Coastal:								
Oregon	8,593	4,153	2,527	1,626	–	–	629	3,811
Washington	1,620	303	138	–	165	–	201	1,116
Total	10,213	4,456	2,665	1,626	165	–	830	4,927
11. Puget Sound:								
Washington	6,071	1,697	1,557	9	69	62	961	3,413
12. Oregon Closed Basin:								
Oregon	1,580	1,215	1,193	22	–	–	2	363
Grand total	70,248	41,612	35,985	3,121	2,416	90	4,416	24,220[2 3]

[1] Individual State statistics not available.
[2] Includes Coeur d'Alene Indian Reservation (22,000 acres).
[3] Contains a negligible amount of county and municipal land.
[4] Less than 500 acres.

Table 29.—Area of commercial forest land, by stand-size class and ownership,

(In

Subregion and State	All size classes			Sawtimber		
	Total	Public	Private	Total	Public	Private
1. Clark Fork-Kootenai-Spokane:						
Idaho and Montana[1]	14,560	10,227	4,333[2]	8,998	6,060	2,938
Washington	1,177	560	617	497	294	203
Total	15,737	10,787	4,950	9,495	6,354	3,141
2. Upper Columbia:						
Washington	4,881	3,622	1,259	3,430	2,806	624
3. Yakima:						
Washington	1,645	1,208	437	1,523	1,134	389
4. Upper Snake:						
Idaho and Wyoming[1]	2,225	2,054	171	1,847	1,711	136
5. Central Snake:						
Idaho	3,004	2,644	360	2,687	2,365	322
Oregon	673	529	144	505	430	75
Total	3,677	3,173	504	3,192	2,795	397
6. Lower Snake:						
Idaho	7,059	5,966	1,093	4,789	3,915	874
Oregon	1,657	1,084	573	1,325	879	446
Washington	165	113	52	138	91	47
Total	8,881	7,163	1,718	6,252	4,885	1,367
7. Mid-Columbia:						
Oregon	5,215	4,005	1,210	3,604	2,819	785
Washington	693	256	437	493	213	280
Total	5,908	4,261	1,647	4,097	3,032	1,065
8. Lower Columbia:						
Oregon	336	19	317	144	-	144
Washington	3,199	1,412	1,787	1,985	1,036	949
Total	3,535	1,431	2,104	2,129	1,036	1,093
9. Willamette:						
Oregon	5,895	3,168	2,727	3,752	2,443	1,309
10. Coastal:						
Oregon	8,593	4,782	3,811	5,425	3,568	1,857
Washington	1,620	504	1,116	789	281	508
Total	10,213	5,286	4,927	6,214	3,849	2,365
11. Puget Sound:						
Washington	6,071	2,658	3,413	3,269	1,806	1,463
12. Oregon Closed Basin:						
Oregon	1,580	1,217	363	1,155	882	273
Grand total	70,248	46,028	24,220	46,355	32,733	13,622

[1] Individual State statistics not available.
[2] Includes Coeur d'Alene Indian Reservation.
[3] Less than 500 acres.

subregion, and State in the Columbia-North Pacific Region, January 1, 1966

thousand acres)

Poletimber			Saplings and seedlings			Nonstocked		
Total	Public	Private	Total	Public	Private	Total	Public	Private
3,653	2,778	875	1,400	1,017	383	509	372	137
413	131	282	203	115	88	64	20	44
4,066	2,909	1,157	1,603	1,132	471	573	392	181
972	501	471	385	261	124	94	54	40
90	56	34	26	15	11	6	3	3
261	235	26	104	96	8	13	12	1
65	54	11	213	188	25	39	37	2
137	73	64	25	21	4	6	5	1
202	127	75	238	209	29	45	42	3
1,111	1,085	26	654	536	118	505	430	75
305	185	120	14	7	7	13	13	(3)
24	20	4	1	–	1	2	2	(3)
1,440	1,290	150	669	543	126	520	445	75
1,113	809	304	401	303	98	97	74	23
171	33	138	19	5	14	10	5	5
1,284	842	442	420	308	112	107	79	28
84	19	65	108	–	108	–	–	–
390	152	238	728	186	542	96	38	58
474	171	303	836	186	650	96	38	58
586	326	260	1,377	331	1,046	180	68	112
759	415	344	1,860	549	1,311	549	250	299
388	116	272	374	78	296	69	29	40
1,147	531	616	2,234	627	1,607	618	279	339
1,883	540	1,343	843	272	571	76	40	36
265	225	40	118	77	41	42	33	9
12,670	7,753	4,917	8,853	4,057	4,796	2,370	1,485	885

Table 30.—Volume of timber on commercial forest land, by class of timber, softwoods an

(In millio

Subregion and State	Total all timber			Growing-stoc					
				Total			Sawtimber		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods
1. Clark Fork-Kootenai-Spokane:									
Idaho and Montana	28,589[1]	28,481[1]	108[1]	28,589	28,481	108	19,071	19,013	58
Washington	1,924	1,899	25	1,808	1,783	25	1,118	1,112	6
Total	30,513	30,380	133	30,397	30,264	133	20,189	20,125	64
2. Upper Columbia:									
Washington	9,870	9,773	97	9,296	9,227	69	6,624	6,595	29
3. Yakima:									
Washington	6,339	6,314	25	6,203	6,178	25	5,329	5,319	10
4. Upper Snake:									
Idaho and Wyoming	4,350[1]	4,284	66[1]	4,350	4,284	66	2,747	2,726	21
5. Central Snake:									
Idaho	5,599[1]	5,593[1]	6[1]	5,599	5,593	6	4,527	4,525	2
Oregon	1,542	1,538	4	1,516	1,512	4	1,261	1,258	3
Total	7,141	7,131	10	7,115	7,105	10	5,788	5,783	5
6. Lower Snake:									
Idaho	14,770[1]	14,747[1]	23[1]	14,770	14,747	23	10,338	10,332	6
Oregon	3,744	3,723	21	3,696	3,677	19	2,762	2,754	8
Washington	407	407	([3])	400	400	–	302	302	–
Total	18,921	18,877	44	18,866	18,824	42	13,402	13,388	14
7. Mid-Columbia:									
Oregon	12,593	12,525	68	12,238	12,206	32	9,719	9,708	11
Washington	1,523	1,512	11	1,504	1,495	9	1,253	1,250	3
Total	14,116	14,037	79	13,742	13,701	41	10,972	10,958	14
8. Lower Columbia:									
Oregon	722	513	209	712	512	200	445	340	105
Washington	17,262	16,224	1,038	15,918	15,005	913	14,133	13,662	471
Total	17,984	16,737	1,247	16,630	15,517	1,113	14,578	14,002	576
9. Willamette:									
Oregon	29,825	27,959	1,866	28,725	27,020	1,705	25,795	24,808	987
10. Coastal:									
Oregon	39,046	34,722	4,324	37,128	33,386	3,742	33,468	31,159	2,309
Washington	8,129	7,405	724	7,681	6,981	700	6,366	6,020	346
Total	47,175	42,127	5,048	44,809	40,367	4,442	39,834	37,179	2,655
11. Puget Sound:									
Washington	27,349	25,119	2,230	26,463	24,375	2,088	22,717	21,608	1,109
12. Oregon Closed Basin:									
Oregon	3,300	3,291	9	3,187	3,180	7	2,794	2,793	1
Grand total	216,883	206,029	10,854	209,783	200,042	9,741	170,769	165,284	5,485

[1] Does not include estimates of cull and salvable dead tree volume.
[2] Data not available.
[3] Less than 300,000 cubic feet.

hardwoods, subregion, and State in the Columbia-North Pacific Region, January 1, 1966

cubic feet)

trees											
Poletimber			Rough (sound cull) trees			Rotten cull trees			Salvable dead trees		
All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods
9,518	9,468	50	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
690	671	19	7	7	(3)	65	65	(3)	44	44	
10,208	10,139	69	7	7	(3)	65	65	(3)	44	44	
2,672	2,632	40	221	199	22	96	91	5	257	256	1
874	859	15	6	6	(3)	17	17	(3)	113	113	(3)
1,603	1,558	45	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1,072	1,068	4	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
255	254	1	10	10	(3)	1	1	(3)	15	15	
1,327	1,322	5	10	10	(3)	1	1	(3)	15	15	
4,432	4,415	17									
934	923	11	15	13	2	9	9	(3)	24	24	
98	98	(3)	1	1	(3)	5	5	(3)	1	1	(3)
5,464	5,436	28	16	14	2	14	14	–	25	25	–
2,519	2,498	21	149	113	36	39	39	(3)	167	167	(3)
251	245	6	2	1	1	10	9	1	7	7	
2,770	2,743	27	151	114	37	49	48	1	174	174	(3)
267	172	95	9		9				1	1	
1,785	1,343	442	174	85	89	22	21	1	1,148	1,113	35
2,052	1,515	537	183	85	98	22	21	1	1,149	1,114	35
2,930	2,212	718	248	102	146	79	76	3	773	761	12
3,660	2,227	1,433	675	143	532	115	93	22	1,128	1,100	28
1,315	961	354	40	18	22	46	46		362	360	2
4,975	3,188	1,787	715	161	554	161	139	22	1,490	1,460	30
3,746	2,767	979	161	41	120	87	77	10	638	626	12
393	387	6	38	36	2	13	13	–	62	62	(3)
39,014	34,758	4,256	1,756	775	981	604	562	42	4,740	4,650	90

Table 31.—Volume of sawtimber on commercial forest land, by species

(Million board feet,

Subregion and State	Total			Douglas-fir	True firs	Lodge-pole pine	Ponderosa and Jeffrey pines	Western white pine	Sugar pine
	All species	Soft-woods	Hard-woods						
1. Clark Fork-Kootenai-Spokane: Idaho and Montana	109,741	109,449	292	29,726	12,351	5,196	11,994	7,700	
Washington	6,061	6,032	29	1,428	684	274	1,017	539	–
Total	115,802	115,481	321	31,154	13,035	5,470	13,011	8,239	–
2. Upper Columbia: Washington	37,266	37,101	165	13,920	3,513	810	10,614	432	–
3. Yakima: Washington	29,168	29,118	50	9,044	5,804	960	7,396	648	–
4. Upper Snake: Idaho and Wyoming	15,684	15,579	105	7,461	1,326	3,720	46		
5. Central Snake: Idaho	27,285	27,275	10	10,027	3,990	1,220	8,694	–	–
Oregon	7,213	7,194	19	1,407	1,285	129	3,283	4	–
Total	34,498	34,469	29	11,434	5,275	1,349	11,977	4	–
6. Lower Snake: Idaho	58,223	58,193	30	16,300	13,654	3,062	4,319	4,669	–
Oregon	14,860	14,820	40	3,677	3,167	601	4,057	9	–
Washington	1,474	1,474	([1])	424	319	12	487	–	–
Total	74,557	74,487	70	20,401	17,140	3,675	8,863	4,678	–
7. Mid-Columbia: Oregon	55,396	55,340	56	12,785	8,548	1,643	24,215	311	–
Washington	6,568	6,562	6	2,629	870	26	2,658	29	–
Total	61,964	61,902	62	15,414	9,418	1,669	26,873	340	–
8. Lower Columbia: Oregon	2,441	1,858	583	1,615	–	–	–	–	–
Washington	94,130	91,389	2,741	51,635	12,500	56	37	646	–
Total	96,571	93,247	3,324	53,250	12,500	56	37	646	–
9. Willamette: Oregon	168,542	163,088	5,454	118,187	9,563	287	327	1,690	285
10. Coastal: Oregon	222,866	209,947	12,919	147,030	13,815	426	3,585	1,614	4,480
Washington	37,499	35,760	1,739	4,980	3,527	33	–	195	–
Total	260,365	245,707	14,658	152,010	17,342	459	3,585	1,809	4,480
11. Puget Sound: Washington	134,589	129,041	5,548	30,744	27,965	48	10	596	–
12. Oregon Closed Basin: Oregon	16,709	16,706	3	122	2,659	838	12,780	77	38
Grand total	1,045,715	1,015,926	29,789	463,144	125,540	19,341	95,519	19,159	4,803

[1] Less than 500,000 board feet.

group, subregion, and State in the Columbia-North Pacific Region, January 1, 1966

International 1/4-inch rule)

Western larch	Redwood	Sitka spruce	Engelmann or other spruce	Western hemlock	Western red-cedar	Incense-cedar	Other soft-woods	Cotton-wood and aspen	Red alder	Oak	Bigleaf maple	Other hard-woods
19,357	–	–	13,126	–	5,048		4,951	196				96
928	–	–	426	408	328	–	–	13	–	–	–	16
20,285	–	–	13,552	408	5,376	–	4,951	209	–	–	–	112
4,023	–	–	2,369	624	448	–	348	157	–	–	–	8
1,792	–	–	850	1,799	151	–	674	49	–	1	–	–
–	–	–	2,728	–	–	–	298	105	–	–	–	–
212	–	–	2,923	–	–	–	209	10	–	–	–	–
762	–	–	322	–	–	–	2	18	–	–	–	1
974	–	–	3,245	–	–	–	211	28	–	–	–	1
2,810	–	–	7,348	264	4,521	–	1,246	30	–	–	–	–
2,110	–	–	1,154	–	–	–	45	40	–	–	–	–
130	–	–	102	–	–	–	–	(1)	–	–	–	(1)
5,050	–	–	8,604	264	4,521	–	1,291	70	–	–	–	–
2,591	–	–	1,739	1,114	199	61	2,134	10	11	23	9	3
241	–	–	76	2	31	–	–	(1)	1	5	–	(1)
2,832	–	–	1,815	1,116	230	61	2,134	10	12	28	9	3
–	–	–	–	101	142	–	–	–	478	–	105	–
55	–	213	187	20,169	4,878	6	1,007	114	1,621	–	955	51
55	–	213	187	20,270	5,020	6	1,007	114	2,099	–	1,060	51
110	–	323	243	23,243	4,521	518	3,791	266	2,625	554	1,508	501
–	267	5,601	90	22,085	3,021	3,874	4,059	113	6,227	3,025	1,490	2,064
–	–	2,478	–	20,436	3,963	–	148	1	1,694	–	44	–
–	267	8,079	90	42,521	6,984	3,874	4,207	114	7,921	3,025	1,534	2,064
–	–	1,734	98	53,948	9,668	–	4,230	500	3,733	1	1,201	113
–	–	–	–	–	–	152	40	3	–	–	–	–
35,121	267	10,349	33,781	144,193	36,919	4,611	23,182	1,625	16,390	3,609	5,312	2,853

Table 32.—Volume of growing stock on commercial forest land, by species group,

(Million

Subregion and State	Total			Douglas-fir	True firs	Lodge-pole pine	Ponderosa and Jeffrey pines	Western white pine	Sugar pine
	All species	Soft-woods	Hard-woods						
1. Clark Fork-Kootenai-Spokane:									
Idaho and Montana	28,589	28,481	108	7,166	3,663	4,724	2,243	1,735	–
Washington	1,808	1,783	25	431	195	257	248	123	–
Total	30,397	30,264	133	7,597	3,858	4,981	2,491	1,858	–
2. Upper Columbia:									
Washington	9,296	9,227	69	3,339	1,174	822	2,037	86	–
3. Yakima:									
Washington	6,203	6,178	25	1,788	1,517	307	1,317	149	
4. Upper Snake:									
Idaho and Wyoming	4,350	4,284	66	1,557	441	1,671	8		
5. Central Snake:									
Idaho	5,599	5,593	6	1,939	998	549	1,481	–	–
Oregon	1,516	1,512	4	314	305	79	605	1	
Total	7,115	7,105	10	2,253	1,303	628	2,086	1	–
6. Lower Snake:									
Idaho	14,770	14,747	23	3,767	3,497	1,989	769	974	–
Oregon	3,696	3,677	19	752	892	440	877	2	–
Washington	400	400	([1])	105	105	18	110	–	–
Total	18,866	18,824	42	4,624	4,494	2,447	1,756	976	–
7. Mid-Columbia:									
Oregon	12,238	12,206	32	2,532	2,252	1,259	4,506	61	–
Washington	1,504	1,495	9	613	273	13	504	6	–
Total	13,742	13,701	41	3,145	2,525	1,272	5,010	67	-
8. Lower Columbia:									
Oregon	712	512	200	441	–	–	–	–	–
Washington	15,918	15,005	913	8,109	2,339	26	9	116	–
Total	16,630	15,517	1,113	8,550	2,339	26	9	116	–
9. Willamette:									
Oregon	28,725	27,020	1,705	18,611	2,112	127	56	292	50
10. Coastal:									
Oregon	37,128	33,386	3,742	22,166	2,610	240	669	279	754
Washington	7,681	6,981	700	1,068	618	8	–	50	–
Total	44,809	40,367	4,442	23,234	3,228	248	669	329	754
11. Puget Sound:									
Washington	26,463	24,375	2,088	6,283	5,350	37	1	139	–
12. Oregon Closed Basin:									
Oregon	3,187	3,180	7	28	599	338	2,144	13	7
Grand total	209,783	200,042	9,741	81,009	28,940	12,904	17,584	4,026	811

[1] Less than 500,000 cubic feet.

subregion, and State in the Columbia-North Pacific Region, January 1, 1966

cubic feet)

Western larch	Redwood	Sitka spruce	Engelmann or other spruce	Western hemlock	Western red-cedar	Incense-cedar	Other soft-woods	Cotton-wood and aspen	Red alder	Oak	Bigleaf maple	Other hard-woods
3,910	–	–	2,615	–	1,248	–	1,177	58	–	–	–	50
254	–	–	107	94	74	–	–	10	–	–	–	15
4,164	–	–	2,722	94	1,322	–	1,177	68	–	–	–	65
842	–	–	578	131	114	–	104	49	3	–	–	17
363	–	–	179	347	36	–	175	24	–	1	–	–
–	–	–	524	–	–	–	83	66	–	–	–	–
36	–	–	546	–	–	–	44	6	–	–	–	–
149	–	–	58	–	–	–	1	4	–	–	–	(1)
185	–	–	604	–	–	–	45	10	–	–	–	(1)
622	–	–	1,543	95	1,091	–	400	10	–	–	–	13
421	–	–	280	–	–	–	13	12	3	–	–	4
30	–	–	32	–	–	–	–	–	–	–	–	(1)
1,073	–	–	1,855	95	1,091	–	413	22	3	–	–	17
499	–	–	384	198	30	16	469	6	9	6	7	4
53	–	–	26	1	6	–	–	–	1	8	–	(1)
552	–	–	410	199	36	16	469	6	10	14	7	4
–	–	–	–	21	50	–	–	–	180	2	18	–
10	–	37	40	3,359	778	1	181	23	639	(1)	233	18
10	–	37	40	3,380	828	1	181	23	819	2	251	18
13	–	57	102	3,855	851	103	791	40	725	348	472	120
–	39	1,111	20	3,635	481	639	743	16	1,627	870	314	915
–	–	390	–	4,085	735	–	27	–	657	–	43	–
–	39	1,501	20	7,720	1,216	639	770	16	2,284	870	357	915
–	–	253	19	9,390	1,968	–	935	89	1,572	1	352	74
–	–	–	–	–	–	39	12	7	–	–	–	–
7,202	39	1,848	7,053	25,211	7,462	798	5,155	420	5,416	1,236	1,439	1,230

Table 33.—Volume of sawtimber on commercial forest land, by ownership, softwoods and hardwoods, subregion, and State in the Columbia-North Pacific Region, January 1, 1966

(Million board feet, International 1/4-inch rule)

Subregion and State	All ownerships			National Forest			Other public			Private		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods
1. Clark Fork-Kootenai-Spokane:												
Idaho and Montana	109,741	109,449	292	66,778	66,713	65	9,902	9,876	26	33,061	32,860	201
Washington	6,061	6,032	29	3,334	3,319	15	377	376	1	2,350	2,337	13
Total	115,802	115,481	321	70,112	70,032	80	10,279	10,252	27	35,411	35,197	214
2. Upper Columbia:												
Washington	37,266	37,101	165	20,862	20,835	27	10,836	10,782	54	5,568	5,484	84
3. Yakima:												
Washington	29,168	29,118	50	13,473	13,473	(1)	9,339	9,326	13	6,356	6,319	37
4. Upper Snake:												
Idaho and Wyoming	15,684	15,579	105	15,227	15,128	99	162	161	1	295	290	5
5. Central Snake:												
Idaho	27,285	27,275	10	26,057	26,047	10	467	467	(1)	761	761	(1)
Oregon	7,213	7,194	19	6,198	6,184	14	185	185	(1)	830	825	5
Total	34,498	34,469	29	32,255	32,231	24	652	652	(1)	1,591	1,586	5
6. Lower Snake:												
Idaho	58,223	58,193	30	42,378	42,348	30	4,966	4,966	(1)	10,879	10,879	(1)
Oregon	14,860	14,820	40	11,642	11,639	3	107	107	-	3,111	3,074	37
Washington	1,474	1,474	(1)	1,174	1,174		22	22	–	278	278	–
Total	74,557	74,487	70	55,194	55,161	33	5,095	5,095	(1)	14,268	14,231	37

Table 33.—Volume of sawtimber on commercial forest land, by ownership, softwoods and hardwoods, subregion, and State in the Columbia-North Pacific Region, January 1, 1966—Continued

(Million board feet, International 1/4-inch rule)

Subregion and State	All ownerships			National Forest			Other public			Private		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods
7. Mid-Columbia:												
Oregon	55,396	55,340	56	42,371	42,350	21	6,468	6,451	17	6,557	6,539	18
Washington	6,568	6,562	6	1,749	1,749		1,563	1,561	2	3,256	3,252	4
Total	61,964	61,902	62	44,120	44,099	21	8,031	8,012	19	9,813	9,791	22
8. Lower Columbia:												
Oregon	2,441	1,858	583		–	–	59	45	14	2,382	1,813	569
Washington	94,130	91,389	2,741	44,716	44,593	123	9,364	8,996	368	40,050	37,800	2,250
Total	96,571	93,247	3,324	44,716	44,593	123	9,423	9,041	382	42,432	39,613	2,819
9. Willamette:												
Oregon	168,542	163,088	5,454	104,495	103,367	1,128	24,081	23,355	726	39,966	36,366	3,600
10. Coastal:												
Oregon	222,866	209,947	12,919	88,929	86,776	2,153	64,435	61,216	3,219	69,502	61,955	7,547
Washington	37,499	35,760	1,739	3,720	[2]	[2]	7,689	[2]	[2]	26,090	[2]	[2]
Total	260,365	245,707	14,658	92,649	[2]	[2]	72,124	[2]	[2]	95,592	[2]	[2]
11. Puget Sound:												
Washington	134,589	129,041	5,548	59,619	[2]	[2]	26,714	[2]	[2]	48,256	[2]	[2]
12. Oregon Closed Basin:												
Oregon	16,709	16,706	3	13,101	13,098	3	132	132	0	3,476	3,476	0
Grand total	1,045,715	1,015,926	29,789	565,823	[2]	[2]	176,868	[2]	[2]	303,024	[2]	[2]

[1] Less than 500,000 board feet.
[2] Data not available.

Table 34.—Volume of growing stock on commercial forest land, by ownership, softwoods and hardwoods, subregion, and State in the Columbia-North Pacific Region, January 1, 1966

(In million cubic feet)

Subregion and State	All ownerships			National Forest			Other public			Private		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods
1. Clark Fork-Kootenai-Spokane:												
Idaho and Montana	28,589	28,481	108	17,460	17,434	26	2,670	2,661	9	8,459	8,386	73
Washington	1,808	1,783	25	858	853	5	121	118	3	829	812	17
Total	30,397	30,264	133	18,318	18,287	31	2,791	2,779	12	9,288	9,198	90
2. Upper Columbia:												
Washington	9,296	9,227	69	5,085	5,074	11	2,644	2,625	19	1,567	1,528	39
3. Yakima:												
Washington	6,203	6,178	25	2,910	2,910	(1)	1,928	1,918	10	1,365	1,350	15
4. Upper Snake:												
Idaho and Wyoming	4,350	4,284	66	4,230	4,168	62	41	40	1	79	76	3
5. Central Snake:												
Idaho	5,599	5,593	6	5,316	5,310	6	108	108	(1)	175	175	(1)
Oregon	1,516	1,512	4	1,249	1,246	3	46	46	(1)	221	220	1
Total	7,115	7,105	10	6,565	6,556	9	154	154	(1)	396	395	1
6. Lower Snake:												
Idaho	14,770	14,747	23	10,878	10,868	10	1,235	1,231	4	2,657	2,648	9
Oregon	3,696	3,677	19	2,780	2,778	2	29	29	0	887	870	17
Washington	400	400	(1)	311	311	–	7	7	(1)	82	82	(1)
Total	18,866	18,824	42	13,969	13,957	12	1,271	1,267	4	3,626	3,600	26

Table 34.—Volume of growing stock on commercial forest land, by ownership, softwoods and hardwoods, subregion, and State in the Columbia-North Pacific Region, January 1, 1966—Continued

(In million cubic feet)

Subregion and State	All ownerships			National Forest			Other public			Private		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard-woods
7. Mid-Columbia:												
Oregon	12,238	12,206	32	9,083	9,072	11	1,396	1,392	4	1,759	1,742	17
Washington	1,504	1,495	9	441	440	1	326	322	4	737	733	4
Total	13,742	13,701	41	9,524	9,512	12	1,722	1,714	8	2,496	2,475	21
8. Lower Columbia:												
Oregon	712	512	200	-			47	34	13	665	478	187
Washington	15,918	15,005	913	7,323	7,277	46	1,620	1,482	138	6,975	6,246	729
Total	16,630	15,517	1,113	7,323	7,277	46	1,667	1,516	151	7,640	6,724	916
9. Willamette:												
Oregon	28,725	27,020	1,705	17,289	16,943	346	4,077	3,833	244	7,359	6,244	1,115
10. Coastal:												
Oregon	37,128	33,386	3,742	14,060	13,312	748	10,901	9,846	1,055	12,167	10,228	1,939
Washington	7,681	6,981	700	696	[2]	[2]	1,688	[2]	[2]	5,297	[2]	[2]
Total	44,809	40,367	4,442	14,756	[2]	[2]	12,589	[2]	[2]	17,464	[2]	[2]
11. Puget Sound:												
Washington	26,463	24,375	2,088	10,891	[2]	[2]	5,146	[2]	[2]	10,426	[2]	[2]
12. Oregon Closed Basin:												
Oregon	3,187	3,180	7	2,440	2,437	3	28	28	0	719	715	4
Grand total	209,783	200,042	9,741	113,300	[2]	[2]	34,058	[2]	[2]	62,425	[2]	[2]

[1] Less than 500,000 cubic feet.
[2] Data not available.

Table 35.—Total wood fiber consumption in the Columbia-North Pacific Region, by State and by industry group, 1965, with projections to the year 2020

(In million cubic feet)

State and industry group	1965	1970	1980	1990	2000	2010	2020
Eastern Washington:							
Lumber and wood products	218	247	297	322	344	351	368
Woodpulp	37	40	45	50	55	60	70
Total	255	287	342	372	399	411	438
Western Washington:							
Lumber and wood products	775	816	897	848	857	828	707
Woodpulp	507	535	721	978	1,051	1,125	1,150
Total	1,282	1,351	1,618	1,826	1,908	1,953	1,857
Eastern Oregon:							
Lumber and wood products	238	245	263	272	281	286	290
Woodpulp	7	10	15	31	38	41	41
Total	245	255	278	303	319	327	331
Idaho:							
Lumber and wood products	328	345	370	399	397	384	357
Woodpulp	48	57	72	101	115	146	185
Total	376	402	442	500	512	530	542
Montana:							
Lumber and wood products	239	218	215	217	173	180	175
Woodpulp	52	84	116	130	185	192	200
Total	291	302	331	347	358	372	375
Western Oregon:							
Lumber and wood products	1,701	1,345	1,195	1,144	1,175	1,166	1,227
Woodpulp	188	285	400	480	508	518	528
Total	1,889	1,630	1,595	1,624	1,683	1,684	1,755
All C-NP Regions:							
Lumber and wood products	3,499	3,216	3,237	3,202	3,227	3,195	3,124
Woodpulp	839	1,011	1,369	1,770	1,952	2,082	2,174
Total	4,338	4,227	4,606	4,972	5,179	5,277	5,298

Table 36.—Total wood fiber consumption in western Washington portion of the Columbia-North Pacific Region, by subregion and type of consumption, 1965, with projections to the year 2020

(In million cubic feet)

Subregion and type of consumption	1965	1970	1980	1990	2000	2010	2020
Lower Columbia (8):							
Saw logs	154	127	118	104	123	124	102
Veneer logs	47	47	62	67	78	86	90
Miscellaneous wood products	15	16	20	23	23	23	20
Pulpwood	229	242	326	442	475	508	519
Foreign log exports	12	24	29	25	17	10	4
Total	457	456	555	661	716	751	735
Coastal (10):							
Saw logs	70	58	53	48	56	57	47
Veneer logs	18	19	24	27	31	34	35
Miscellaneous wood products	7	8	9	11	11	11	9
Pulpwood	37	39	53	72	77	83	85
Foreign log exports	46	90	110	93	61	38	15
Total	178	214	249	251	236	223	191
Puget Sound (11):							
Saw logs	232	191	178	158	185	188	155
Veneer logs	93	94	122	135	156	171	179
Miscellaneous wood products	22	25	30	36	36	36	31
Pulpwood	241	254	342	464	499	534	546
Foreign log exports	59	117	142	121	80	50	20
Total	647	681	814	914	956	979	931
Western Washington:							
Saw logs	456	376	349	310	364	369	304
Veneer logs	158	160	208	229	265	291	304
Miscellaneous wood products	44	49	59	70	70	70	60
Pulpwood	507	535	721	978	1,051	1,125	1,150
Foreign log exports	117	231	281	239	158	98	39
Total	1,282	1,351	1,618	1,826	1,908	1,953	1,857

Table 37.—Total wood fiber consumption in eastern Washington portion of the Columbia-North Pacific Region, by subregion and type of consumption, 1965, with projections to the year 2020

(In million cubic feet)

Subregion and type of consumption	1965	1970	1980	1990	2000	2010	2020
Clark Fork-Kootenai-Spokane (1):							
Saw logs	27	29	34	36	38	38	39
Veneer logs	–	–	–	–	–	–	–
Miscellaneous wood products	2	2	2	2	2	2	2
Pulpwood	7	8	8	9	9	10	12
Total	36	39	44	47	49	50	53
Upper Columbia (2):							
Saw logs	85	90	108	115	121	119	123
Veneer logs		8	10	13	15	18	20
Miscellaneous wood products	7	7	7	7	7	7	7
Pulpwood	3	3	8	11	13	17	20
Foreign log exports	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Total	95	108	133	146	156	161	170
Yakima (3):							
Saw logs	42	44	53	56	60	59	60
Veneer logs	9	15	19	24	28	33	37
Miscellaneous wood products	3	3	3	3	3	3	3
Pulpwood	–	–	–	–	–	–	–
Total	54	62	75	83	91	95	100
Lower Snake (6):							
Saw logs	(1)	(1)	1	1	1	1	1
Veneer logs	–	–	–	–	–	–	–
Miscellaneous wood products	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Pulpwood	–	–	–	–	–	–	–
Total	–	–	1	1	1	1	1
Mid-Columbia (7):							
Saw logs	35	37	45	48	50	49	50
Veneer logs	5	9	12	14	16	19	23
Miscellaneous wood products	3	3	3	3	3	3	3
Pulpwood	27	29	29	30	33	33	38
Total	70	78	89	95	102	104	114
Eastern Washington:							
Saw logs	189	200	241	256	270	266	273
Veneer logs	14	32	41	51	59	70	80
Miscellaneous wood products	15	15	15	15	15	15	15
Pulpwood	37	40	45	50	55	60	70
Foreign log exports	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Total	255	287	342	372	399	411	438

[1] Less than 500,000 cubic feet.

Table 38.—Total wood fiber consumption in the western Oregon portion of the Columbia-North Pacific Region, by subregion and type of consumption, 1965, with projections to the year 2020

(In million cubic feet)

Subregion and type of consumption	1965	1970	1980	1990	2000	2010	2020
Mid-Columbia (7):							
Saw logs	23	16	13	11	10	10	12
Veneer logs	–	–	–	–	–	–	
Miscellaneous wood products	1	1	1	1	2	2	2
Pulpwood	4	5	7	9	10	10	10
Foreign log exports	–	–	–	–	–	–	–
Total	28	22	21	21	22	22	24
Lower Columbia (8):							
Saw logs	51	37	28	25	24	24	26
Veneer logs	13	11	11	11	12	12	13
Miscellaneous wood products	2	2	3	3	4	4	4
Pulpwood	20	30	42	51	54	55	56
Foreign log exports	–	–	–	–	–	–	–
Total	86	80	84	90	94	95	99
Willamette (9):							
Saw logs	492	350	272	242	230	230	253
Veneer logs	316	269	269	269	302	304	314
Miscellaneous wood products	20	22	26	31	35	35	35
Pulpwood	95	145	203	243	257	262	267
Foreign log exports	8	13	13	13	8	5	4
Total	931	799	783	798	832	836	873
Coastal (10):							
Saw logs	432	307	238	212	202	202	221
Veneer logs	301	256	256	256	286	289	298
Miscellaneous wood products	17	19	22	27	31	31	31
Pulpwood	69	105	148	177	187	191	195
Foreign log exports	25	42	43	43	29	18	14
Total	844	729	707	715	735	731	759
Western Oregon:							
Saw logs	998	710	551	490	466	466	512
Veneer logs	630	536	536	536	600	605	625
Miscellaneous wood products	40	44	52	62	72	72	72
Pulpwood	188	285	400	480	508	518	528
Foreign log exports	33	55	56	56	37	23	18
Total	1,889	1,630	1,595	1,624	1,683	1,684	1,755

Table 39.—Total wood fiber consumption in the eastern Oregon portion of the Columbia-North Pacific Region, by subregion and type of consumption, 1965, with projections to the year 2020

(In million cubic feet)

Subregion and type of consumption	1965	1970	1980	1990	2000	2010	2020
Central Snake (5):							
Saw logs	11	10	10	10	10	10	10
Veneer logs	1	2	3	4	5	5	5
Miscellaneous wood products	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Pulpwood	—	—	—	—	—	—	—
Total	12	12	13	14	15	15	15
Lower Snake (6):							
Saw logs	37	37	37	37	37	37	37
Veneer logs	8	12	18	22	25	27	28
Miscellaneous wood products	1	1	1	1	1	1	1
Pulpwood	—	—	—	—	—	—	—
Total	46	50	56	60	63	65	66
Mid-Columbia (7):							
Saw logs	137	136	136	136	136	136	136
Veneer logs	12	16	26	30	35	38	40
Miscellaneous wood products	3	3	3	3	3	3	3
Pulpwood	7	10	15	31	38	41	41
Total	159	165	180	200	212	218	220
Oregon Closed Basin (12):							
Saw logs	27	27	27	27	27	27	27
Veneer logs	1	1	2	2	2	2	3
Miscellaneous wood products	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Pulpwood	—	—	—	—	—	—	—
Total	28	28	29	29	29	29	30
Eastern Oregon:							
Saw logs	212	210	210	210	210	210	210
Veneer logs	22	31	49	58	67	72	76
Miscellaneous wood products	4	4	4	4	4	4	4
Pulpwood	7	10	15	31	38	41	41
Total	245	255	278	303	319	327	331

[1] Less than 500,000 cubic feet.

Table 40.—Total wood fiber consumption in the Idaho portion of the Columbia-North Pacific Region, by subregion and type of consumption, 1965, with projections to the year 2020

(In million cubic feet)

Subregion and type of consumption	1965	1970	1980	1990	2000	2010	2020
Clark Fork-Kootenai-Spokane (1):							
Saw logs	107	106	111	119	115	107	95
Veneer logs	5	10	13	15	17	19	20
Miscellaneous wood products	5	5	5	5	5	5	5
Pulpwood							
Total	117	121	129	139	137	131	120
Upper Snake (4):							
Saw logs	7	7	8	8	8	8	7
Veneer logs							
Miscellaneous wood products	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Pulpwood					12	24	35
Total	7	7	8	8	20	32	42
Central Snake (5):							
Saw logs	48	47	49	53	51	48	43
Veneer logs	4	8	10	11	13	14	15
Miscellaneous wood products	3	3	3	3	3	3	3
Pulpwood		–	14	36	37	48	75
Total	55	58	76	103	104	113	136
Lower Snake (6):							
Saw logs	131	130	136	146	141	131	117
Veneer logs	11	22	28	32	37	42	45
Miscellaneous wood products	7	7	7	7	7	7	7
Pulpwood	48	57	58	65	66	74	75
Total	197	216	229	250	251	254	244
Idaho:							
Saw logs	293	290	304	326	315	294	262
Veneer logs	20	40	51	58	67	75	80
Miscellaneous wood products	15	15	15	15	15	15	15
Pulpwood	48	57	72	101	115	146	185
Total	376	402	442	500	512	530	542

[1] Less than 500,000 cubic feet.

Table 41.—Total wood fiber consumption in western Montana portion of the Columbia-North Pacific Region, by subregion and type of consumption, 1965, with projections to the year 2020

(In million cubic feet)

Subregion and type of consumption	1965	1970	1980	1990	2000	2010	2020
Western Montana, Clark Fork-Kootenai-Spokane (1):							
Saw logs	195	171	164	161	109	110	102
Veneer logs	34	37	41	46	54	60	63
Miscellaneous wood products	10	10	10	10	10	10	10
Pulpwood	52	84	107	130	185	192	200
Total	291	302	322	347	358	372	375

Table 42.—Forest industry employment in the Columbia-North Pacific Region, by State and industry group, 1965, with projections to the year 2020[1]

(Number of persons)

State and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Eastern Washington:								
Lumber and wood products	24	7,660	8,375	8,192	7,521	6,988	6,418	6,072
Pulp and paper	26	1,131	1,102	1,039	994	960	933	982
Total		8,791	9,477	9,231	8,515	7,948	7,351	7,054
Eastern Oregon:								
Lumber and wood products	24	8,335	7,606	6,763	6,034	5,512	5,046	4,648
Pulp and paper	26	230	294	366	646	691	661	594
Total		8,565	7,900	7,129	6,680	6,203	5,707	5,242
Western Washington:								
Lumber and wood products	24	39,275	33,707	30,736	27,343	26,261	23,736	22,159
Pulp and paper	26	18,658	17,893	19,539	22,278	20,648	19,430	17,719
Total		57,933	51,600	50,275	49,621	46,909	43,166	39,878
Western Oregon:								
Lumber and wood products	24	62,918	49,782	41,047	35,950	33,836	31,269	30,770
Pulp and paper	26	7,282	9,500	10,526	10,667	9,769	8,780	8,000
Total		70,200	59,282	51,573	46,617	43,605	40,049	38,770
Idaho:								
Lumber and wood products	24	11,515	11,386	10,379	9,569	8,207	7,352	6,629
Pulp and paper	26	870	1,014	1,139	1,439	1,490	1,734	2,028
Total		12,385	12,400	11,518	11,008	9,697	9,086	8,657
Western Montana:								
Lumber and wood products	24	7,615	6,447	~~7,163~~	4,996	3,978	3,764	3,538
Pulp and paper	26	300	428	571	619	852	873	866
Total		7,915	6,875	~~7,734~~	5,615	4,830	4,637	4,404
Total C-NP Regions:								
Lumber and wood products	24	137,318	117,303	~~104,280~~	91,413	84,782	77,585	73,816
Pulp and paper	26	28,471	30,231	33,180	36,643	34,410	32,411	30,189
Total		165,789	147,534	~~137,460~~	128,056	119,192	109,996	104,005

[1] Data have not been rounded.

Table 43.—Forest industry employment in western Washington portion of the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Lower Columbia (8):								
Logging	2411	3,560	3,296	3,080	2,783	2,499	1,958	1,921
Sawmills	2421	3,868	2,678	1,823	1,266	1,229	1,060	767
Veneer, plywood	2432	2,395	2,112	2,178	1,988	1,965	1,882	1,745
All other	24	810	814	814	814	814	814	814
Pulp, paper	26	7,555	7,245	7,911	9,020	8,360	7,867	7,174
Total		18,188	16,145	15,806	15,871	14,867	13,581	12,421
Coastal (10):								
Logging	2411	2,909	2,694	2,517	2,274	2,043	1,601	1,570
Sawmills	2421	1,336	926	630	438	425	366	265
Veneer, plywood	2432	1,515	1,335	1,377	1,257	1,243	1,191	1,103
All other	24	1,367	1,373	1,373	1,373	1,373	1,373	1,373
Pulp, paper	26	1,258	1,206	1,317	1,501	1,392	1,310	1,194
Total		8,385	7,534	7,214	6,843	6,476	5,841	5,505
Puget Sound (11):								
Logging	2411	4,501	4,167	3,895	3,518	3,160	2,476	2,430
Sawmills	2421	6,478	4,485	3,052	2,121	2,058	1,776	1,284
Veneer, plywood	2432	6,142	5,414	5,584	5,098	5,039	4,826	4,474
All other	24	4,394	4,413	4,413	4,413	4,413	4,413	4,413
Pulp, paper	26	9,845	9,442	10,311	11,757	10,896	10,253	9,351
Total		31,360	27,921	27,255	26,907	25,566	23,744	21,952
Western Washington:								
Logging	2411	10,970	10,157	9,492	8,575	7,702	6,035	5,921
Sawmills	2421	11,682	8,089	5,505	3,825	3,712	3,202	2,316
Veneer, plywood	2432	10,052	8,861	9,139	8,343	8,247	7,899	7,322
All other	24	6,571	6,600	6,600	6,600	6,600	6,600	6,600
Pulp, paper	26	18,658	17,893	19,539	22,278	20,648	19,430	17,719
Total		57,933	51,600	50,275	49,621	46,909	43,166	39,878

[1] Data have not been rounded.

Table 44.—Forest industry employment in eastern Washington portion of the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Clark Fork-Kootenai-Spokane (1):								
Logging	2411	115	124	124	114	107	102	96
Sawmills	2421	950	953	899	776	685	577	513
Veneer, plywood	2432	–	–	–	–	–	–	–
All other	24	615	688	688	688	688	688	688
Pulp, paper	26	450	428	351	298	288	280	295
Total		2,130	2,193	2,062	1,876	1,768	1,647	1,592
Upper Columbia (2):								
Logging	2411	716	770	771	713	670	632	597
Sawmills	2421	2,042	2,049	1,931	1,667	1,472	1,239	1,101
Veneer, plywood	2432	–	226	248	269	274	290	304
All other	24	47	53	53	53	53	53	53
Pulp, paper	26	83	88	83	80	76	75	79
Total		2,888	3,186	3,086	2,782	2,545	2,289	2,134
Yakima (3):								
Logging	2411	402	432	433	400	376	355	335
Sawmills	2421	1,019	1,023	964	832	734	618	550
Veneer, plywood	2432	255	407	447	484	494	522	548
All other	24	123	137	137	137	137	137	137
Pulp, paper	26	168	165	254	310	300	291	306
Total		1,967	2,164	2,235	2,163	2,041	1,923	1,876
Lower Snake (6):								
Logging	2411	21	22	22	21	20	18	17
Sawmills	2421	47	47	44	38	34	28	25
Veneer, plywood	2432	–	–	–	–	–	–	–
All other	24	–	–	–	–	–	–	–
Pulp, paper	26	–	–	–	–	–	–	–
Total		68	69	66	59	54	46	42
Mid-Columbia (7):								
Logging	2411	384	413	414	382	359	339	320
Sawmills	2421	731	733	691	596	527	444	394
Veneer, plywood	2432	173	276	304	329	336	354	372
All other	24	20	22	22	22	22	22	22
Pulp, paper	26	430	421	351	306	296	287	302
Total		1,738	1,865	1,782	1,635	1,540	1,446	1,410
Eastern Washington:								
Logging	2411	1,638	1,761	1,764	1,630	1,532	1,446	1,365
Sawmills	2421	4,789	4,805	4,529	3,909	3,452	2,906	2,583
Veneer, plywood	2432	428	909	999	1,082	1,104	1,166	1,224
All other	24	805	900	900	900	900	900	900
Pulp, paper	26	1,131	1,102	1,039	994	960	933	982
Total		8,791	9,477	9,231	8,515	7,948	7,351	7,054

[1] Data have not been rounded.

Table 45.—Forest industry employment in western Oregon portion of the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Mid-Columbia (7):								
Logging	2411	86	75	60	51	44	39	36
Sawmills	2421	406	229	130	88	65	52	51
Veneer, plywood	2432	–	–	–	–	–	–	–
All other	24	93	93	93	93	93	93	93
Pulp, paper	26	–	150	167	170	155	140	126
Total		585	547	450	402	357	324	306
Lower Columbia (8):								
Logging	2411	190	166	133	113	98	86	81
Sawmills	2421	604	343	194	132	97	77	77
Veneer, plywood	2432	418	342	315	287	287	267	266
All other	24	23	23	23	23	23	23	23
Pulp, paper	26	908	1,185	1,313	1,330	1,218	1,095	998
Total		2,143	2,059	1,978	1,885	1,723	1,548	1,445
Willamette (9):								
Logging	2411	5,626	4,906	3,929	3,352	2,888	2,557	2,384
Sawmills	2421	9,443	5,945	3,369	2,285	1,687	1,346	1,332
Veneer, plywood	2432	14,446	11,791	10,850	9,872	9,874	9,216	9,155
All other	24	5,050	5,078	5,078	5,078	5,078	5,078	5,078
Pulp, paper	26	5,379	6,866	7,607	7,709	7,060	6,345	5,782
Total		39,944	34,586	30,833	28,296	26,587	24,542	23,731
Coastal (10):								
Logging	2411	5,847	5,100	4,085	3,484	3,003	2,658	2,479
Sawmills	2421	7,739	4,916	2,785	1,890	1,395	1,113	1,102
Veneer, plywood	2432	11,847	9,669	8,897	8,096	8,098	7,558	7,507
All other	24	1,100	1,106	1,106	1,106	1,106	1,106	1,106
Pulp, paper	26	995	1,299	1,439	1,458	1,336	1,200	1,094
Total		27,528	22,090	18,312	16,034	14,938	13,635	13,288
Western Oregon:								
Logging	2411	11,749	10,247	8,207	7,000	6,033	5,340	4,980
Sawmills	2421	18,192	11,433	6,478	4,395	3,244	2,588	2,562
Veneer, plywood	2432	26,711	21,802	20,062	18,255	18,259	17,041	16,928
All other	24	6,266	6,300	6,300	6,300	6,300	6,300	6,300
Pulp, paper	26	7,282	9,500	10,526	10,667	9,769	8,780	8,000
Total		70,200	59,282	51,573	46,617	43,605	40,049	38,770

[1] Data have not been rounded.

Table 46.—Forest industry employment in the eastern Oregon portion of the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Central Snake (5):								
Logging	2411	37	37	36	36	35	33	31
Sawmills	2421	334	281	213	169	140	119	102
Veneer, plywood	2432	163	206	250	238	228	208	190
All other	24	22	20	20	20	20	20	20
Pulp, paper	26	–	–	–	–	–	–	–
Total		556	544	519	463	423	380	343
Lower Snake (6):								
Logging	2411	297	293	290	285	279	268	254
Sawmills	2421	688	578	438	349	288	244	210
Veneer, plywood	2432	231	291	354	337	323	295	269
All other	24	–	–	–	–	–	–	–
Pulp, paper	26	–		–	–	–	–	–
Total		1,216	1,162	1,082	971	890	807	733
Mid-Columbia (7):								
Logging	2411	899	887	876	863	843	810	768
Sawmills	2421	2,958	2,484	1,883	1,501	1,240	1,050	903
Veneer, plywood	2432	358	451	548	523	501	458	417
All other	24	1,143	1,051	1,051	1,051	1,051	1,051	1,051
Pulp, paper	26	230	294	366	646	691	661	594
Total		5,588	5,167	4,724	4,584	4,326	4,030	3,733
Oregon Closed Basin (12):								
Logging	2411	82	81	80	79	77	74	70
Sawmills	2421	1,092	917	695	554	458	387	334
Veneer, plywood	2432	–	–	–	–	–	–	–
All other	24	31	29	29	29	29	29	29
Pulp, paper	26	–	–	–	–	–	–	–
Total		1,205	1,027	804	662	564	490	433
Eastern Oregon:								
Logging	2411	1,315	1,298	1,282	1,263	1,234	1,185	1,123
Sawmills	2421	5,072	4,260	3,229	2,573	2,126	1,800	1,549
Veneer, plywood	2432	752	948	1,152	1,098	1,052	961	876
All other	24	1,196	1,100	1,100	1,100	1,100	1,100	1,100
Pulp, paper	26	230	294	366	646	691	661	594
Total		8,565	7,900	7,129	6,680	6,203	5,707	5,242

[1] Data have not been rounded.

Table 47.—Forest industry employment in the Idaho portion of the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020[1]

(Number of persons)

Subregion and industry group	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Clark Fork-Kootenai-Spokane (1):								
Logging	2411	843	839	818	766	653	604	556
Sawmills	2421	2,434	2,186	1,811	1,582	1,242	993	793
Veneer, plywood	2432	299	571	659	685	708	739	759
All other	24	259	200	200	200	200	200	200
Pulp, paper	26			–	–	–	–	–
Total		3,835	3,796	3,488	3,233	2,803	2,536	2,308
Upper Snake (4):								
Logging	2411	73	73	71	66	56	52	48
Sawmills	2421	203	182	151	132	104	83	66
Veneer, plywood	2432	34	65	75	78	80	84	86
All other	24	–	–	–	–	–	–	–
Pulp, paper	26	70	86	76	71	227	355	454
Total		380	406	373	347	467	574	654
Central Snake (5):								
Logging	2411	342	340	332	311	265	245	226
Sawmills	2421	1,615	1,450	1,201	1,050	824	658	526
Veneer, plywood	2432	494	944	1,089	1,132	1,169	1,220	1,253
All other	24	33	26	26	26	26	26	26
Pulp, paper	26		–	222	513	479	570	822
Total		2,484	2,760	2,870	3,032	2,763	2,719	2,853
Lower Snake (6):								
Logging	2411	1,316	1,309	1,278	1,196	1,020	943	868
Sawmills	2421	3,467	3,114	2,579	2,255	1,769	1,414	1,130
Veneer, plywood	2432	7	13	15	16	17	17	18
All other	24	96	74	74	74	74	74	74
Pulp, paper	26	800	928	841	855	784	809	752
Total		5,686	5,438	4,787	4,396	3,664	3,257	2,842
Idaho:								
Logging	2411	2,574	2,561	2,499	2,339	1,994	1,844	1,698
Sawmills	2421	7,719	6,932	5,742	5,019	3,939	3,148	2,515
Veneer, plywood	2432	834	1,593	1,838	1,911	1,974	2,060	2,116
All other	24	388	300	300	300	300	300	300
Pulp, paper	26	870	1,014	1,139	1,439	1,490	1,734	2,028
Total		12,385	12,400	11,518	11,008	9,697	9,086	8,657

[1] Data have not been rounded.

Table 48.—Forest industry employment in the western Montana portion of the Columbia-North Pacific Region, by subregion and industry group, 1965, with projections to the year 2020

(Number of persons)

Subregion and industry use	Standard industrial classification code	1965	1970	1980	1990	2000	2010	2020
Clark Fork-Kootenai-Spokane (1):								
Logging	2411	1,488	1,425	2,986	1,379	1,236	1,136	1,058
Sawmills	2421	4,740	3,543	2,643	2,051	1,103	937	768
Veneer, plywood	2432	1,296	1,179	1,234	1,266	1,339	1,391	1,412
All other	24	91	300	300	300	300	300	300
Pulp, paper	26	300	428	571	619	852	873	866
Total		7,915	6,875	7,734	5,615	4,830	4,637	4,404

Table 49.—Population, households, gross national product, and disposable personal income in the United States, 1920-62, with projections to the year 2000[1]

Year	Population	Households	Persons per household	Gross national product (1961 dollars)	Disposable personal income (1961 dollars)	
					Total	Per capita
	Million persons	*Million*	*Number*	*Billion dollars*	*Billion dollars*	*Dollars*
1920	106.5	24.4	4.36	143.0	–	–
1930	123.2	29.9	4.12	190.3	140.6	1,141
1940	132.1	34.9	3.79	268.8	170.2	1,288
1950	152.3	43.0	3.54	366.5	256.7	1,685
1960	180.7	53.0	3.41	511.1	355.7	1,968
1962	186.7	54.7	3.41	546.0	379.0	2,030
1970	208.0	62.5	3.33	710.0	500.0	2,400
1975	223.0	–	–	84.0	–	–
1980	241.0	73.5	3.28	990.0	690.0	2,860
1985	260.0	–	–	1,175.0	–	–
1990	280.0	86.2	3.25	1,380.0	960.0	3,430
2000	325.0	101.0	3.22	1,920.00	1,340.0	4,120

Sources: POPULATION: 1920-40, U.S. Bur. Census, "Historical Statistics of the United States," 1960. 1950-62, "Estimates of the Population of the United States, January 1, 1950, to March 1, 1964."

[1] Based on tables 1 and 2, pp. 6 and 8, "Timber Trends in the United States" (U.S.D.A. Forest Service 1965).

Table 50.–Summary of total demand for major timber products in the United States, 1952-62, with projections to the year 1985

Product	Standard unit of measure	1952	1962	1970	1975	1980	1985
Lumber:							
Total	Million board feet	41,460	37,300	39,700	41,600	43,400	45,500
Per capita	Board feet	263	200	191	187	180	175
Plywood and veneer:							
Softwoods	Million square feet, 3/8-inch basis	-	9,250	14,400	15,600	17,000	18,500
Hardwoods	Million square feet, 3/8-inch basis	–	2,770	3,500	4,200	5,000	5,700
Total		–	12,020	17,900	19,800	22,000	24,200
Per capita	Square feet	–	64	86	89	91	93
Woodpulp:							
Total	Million tons	–	29.5	38.2	44.8	52.4	60.5
Paper and board:							
Total	Million tons	–	42.4	52.7	60.2	69.3	79.2
Per capita	Pounds	–	454	507	540	575	609

Source: "Timber Trends in the United States" (U.S.D.A. Forest Service 1965).

Table 51.– Summary of consumption, net imports, and domestic production of timber products in the United States, 1952-62, with projections to the year 1985

Product	Standard unit of measure	1952	1962	1970	1975	1980	1985
Lumber:							
Consumption	Million board feet, International 1/4-inch rule	41,460	37,300	39,700	41,600	43,400	45,500
Net imports	"	1,752	4,130	5,100	5,400	5,800	6,100
Domestic production	"	39,708	33,170	34,600	36,200	37,600	39,400
Domestic roundwood[1]	"	39,480	34,105	35,600	37,200	38,600	40,400
Veneer logs:							
Consumption	"	3,082	6,776	10,300	11,300	12,500	13,900
Net imports[2]	"	148	860	1,300	1,600	1,900	2,300
Domestic production	"	2,934	5,916	9,000	9,700	10,600	11,600
Domestic roundwood	"	2,934	5,916	9,000	9,700	10,600	11,600
Pulpwood:							
Consumption[3]	Million standard cords	35.4	52.8	67.5	78.0	88.5	99.5
Net imports	"	11.0	10.1	11.0	11.2	11.5	12.2
Domestic production	"	25.0	42.8	56.6	66.8	77.8	87.3
Domestic roundwood	"	23.4	33.8	42.0	50.8	60.0	69.3
Miscellaneous industrial wood:							
Consumption	Million cubic feet	758	505	500	500	500	500
Net imports	"	(4)	(4)	–	–	–	–
Domestic production	"	758	505	500	500	500	500
Domestic roundwood	"	699	466	460	460	460	460
Fuelwood:							
Consumption[5]	Million standard cords	58.6	26.9	22.0	20.0	18.0	16.5
Net imports	"	(4)	(4)	–	–	–	–
Domestic production	"	58.6	26.9	22.0	20.0	18.0	16.5
Domestic roundwood	"	27.2	15.0	13.2	12.0	10.8	9.8

Source: "Timber Trends in the United States" U.S D.A. Forest Service 1965).

[1] The difference between domestic production of lumber and domestic roundwood production (saw logs) in 1962 and later years largely reflects the growing practice of converting to pulp chips a portion of the lower grade material in saw logs. The 1952 estimate was based on a special Forest Service survey of log and lumber production.

[2] Including equivalent log volumes of imported veneer and plywood.

[3] Including equivalent log volumes of imported pulp and paper and board, plus plant byproducts.

[4] Less than minimum reporting unit.

[5] Including equivalent log volumes of plant byproducts.

DEFINITION OF THE COLUMBIA-NORTH PACIFIC REGION

Counties in Subregion for Economic Studies

ıbregion name	Idaho	Montana	Oregon	Washington	Wyoming
LARK FORK-OOTENAI-POKANE	Benewah Bonner Boundary Kootenai Shoshone	Deer Lodge Flathead Granite Lake Lincoln Mineral Missoula Powell Ravalli Sanders Silver Bow		Pend Oreille Spokane	
PPER COLUMBIA				Adams Chelan Douglas Ferry Franklin Grant Lincoln Okanogan Stevens	
AKIMA				Benton Kittitas Yakima	
PPER SNAKE	Bannock Bingham Blaine Bonneville Butte Camas Caribou Cassia Clark Fremont Gooding Jefferson Jerome Lincoln Madison Minidoka Power Teton Twin Falls				Teton

	Subregion name	Idaho	Montana	Oregon	Washington	Wyoming
5.	CENTRAL SNAKE	Ada Adams Boise Canyon Elmore Gem Owyhee Payette Valley Washington		Baker Malheur		
6.	LOWER SNAKE	Clearwater Custer Idaho Latah Lemhi Lewis Nez Perce		Union Wallowa	Asotin Garfield Whitman	
7.	MID-COLUMBIA			Crook Deschutes Gilliam Grant Hood River Jefferson Morrow Sherman Umatilla Wasco Wheeler	Columbia Klickitat Walla Walla	
8.	LOWER COLUMBIA			Columbia	Clark Cowlitz Lewis Skamania Wahkiakum	
9.	WILLAMETTE			Benton Clackamas Lane Linn Marion Multnomah Polk Washington Yamhill		

Subregion name	Idaho	Montana	Oregon	Washington	Wyoming
10. COASTAL			Clatsop Coos Curry Douglas Jackson Josephine Lincoln Tillamook	Grays Harbor Pacific	
11. PUGET SOUND				Clallam Island Jefferson King Kitsap Mason Pierce San Juan Skagit Snohomish Thurston Whatcom	
12. OREGON CLOSED BASIN			Harney Lake		

DEFINITION OF TERMS

Commercial forest land.—Forest land which is producing, or is capable of producing, crops of industrial wood and is not withdrawn from timber utilization by statute or administrative regulation. Includes areas suitable for management to grow crops of industrial wood generally capable of producing in excess of 20 cubic feet per acre of annual growth. Includes both accessible and prospectively accessible areas and both operable and prospectively operable areas.

Commercial species.—Tree species presently or prospectively suitable for industrial wood products; excludes so-called weed species such as willow and dogwood.

Cull trees.—Live trees that do not contain at least one merchantable 12-foot saw log, now or prospectively, because of defect, rot, or species (also see "Rotten cull trees").

Diameter classes.—A classification of trees based on diameter of the tree outside bark, measured at breast height. Two-inch diameter classes, in which the even inch is the approximate midpoint, are used.

Diameter at breast height (d.b.h.).—Diameter of a tree measured at breast height (4-1/2 feet above the ground).

Farm.—A place operated as a unit of 10 or more acres from which sale of agricultural products totals $50 or more annually, or a place operated as a unit of less than 10 acres from which the sale of agricultural products totaled $250 or more during the previous year.

Forest industry lands.—Lands owned by companies or individuals operating wood-using plants.

Forest land.—Land at least 10 percent stocked by forest trees of any size, or formerly having such tree cover and not currently developed for nonforest use. Includes chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classed as forest if less than 120 feet in width.

Forest management.—The protection and management of forest lands for the production of timber and related products.

Forest trees.—Woody plants having a well-developed stem and usually more than 12 feet in height, including both growing stock and cull trees.

Forest type.—A classification of forest land based upon the species presently forming a plurality of stocking.

Growing-stock trees.—Live sawtimber trees, poletimber trees, saplings and seedlings meeting specific standards of quality and vigor; excludes cull trees.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Harvesting.—The cutting and transportation of logs and related forest products to local points of delivery.

Indian lands.—Tribal lands held in fee but administered by the Federal Government and Indian trust allotments.

Land area.—Includes dry land and land temporarily or partially covered by water, such as marshes, swamps, and river flood plains; streams, sloughs, and canals less than one-eighth mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

Mill residue (plant residue).—Wood materials from primary manufacturing plants that are not used for some product.

Miscellaneous private lands.—Privately owned lands other than forest industry or farmer owned.

Mortality.—The volume of sound wood in live sawtimber and poletimber trees dying from natural causes during a specific period.

National Forest land.—Federal lands which have been designated by Executive Order or statute as National Forests or purchase units, and other lands under the

administration of the Forest Service, including experimental areas and Bankhead-Jones Title III lands.

Net annual growth.—The annual change in volume of sound wood in live sawtimber and poletimber trees resulting from natural causes; i.e., increases in volume in absence of mortality and cutting, minus mortality, plus growth on mortality, and growth on one-half the cut during a specified year.

Net volume.—The gross volume of a tree less deductions for rot, sweep, or other defects affecting use.

Noncommercial forest land.—Unproductive forest land incapable of yielding crops of industrial wood because of adverse site conditions, and productive forest land withdrawn from commercial timber use through statute or administrative regulation.

Nonforest land.—Land that has never supported forests, and lands formerly forested, where use of timber is precluded by development for nonforest use such as crops, improved pasture, residential areas, and city parks. Also includes improved roads and adjoining rights-of-way, powerline clearings, and certain areas of water classified by the Bureau of Census as land. In forested areas, unimproved roads, streams, canals, and nonforest strips must be more than 120 feet wide and clearings in forest areas must be more than 1 acre in size to qualify as nonforest land.

Nonstocked area.—Commercial forest land less than 10 percent stocked with growing-stock trees.

Ownership.—The property owned by one owner, regardless of the number of parcels that may comprise it, in a specific area such as a State or the United States as a whole.

Other public lands.—Federal lands administered by the Bureau of Land Management, Bureau of Indian Affairs, and miscellaneous Federal agencies; and lands owned by States, counties, and local public agencies, or lands leased by these governmental units for more than 50 years. National Forests are excluded.

Poletimber trees.—Live trees 5.0 to 10.9 inches in diameter at breast height.

Productive-reserved forest land.—Productive public forest land withdrawn from timber utilization through statute or administrative regulation.

Projected demand.—The estimated quantity of a roundwood product, or products, that would be demanded at specified times in the future under explicit assumptions as to (1) the growth of the population and national products, (2) trends in the use of materials, and (3) trends in prices of timber products relative to substitute materials.

Projected employment.—The estimated volume of employment that would be associated with meeting projected demands for a timber product or products at specified times in the future under explicit assumptions as to (1) changes in productivity, i.e., output per employee, and (2) changes in secondary manufacturing activities.

Roundwood (roundwood products).—Logs, bolts, or other round sections cut from trees.

Rotten cull trees.—Live trees of commercial species that do not contain at least one minimum saw log, now or prospectively, primarily because of rot.

Rough trees (sound cull trees).—Live trees, 5.0 inches or larger in diameter at breast height, that do not contain at least one minimum saw log, now or prospectively, and have less than 25 percent of their volume in usable form primarily because of roughness, poor form, or noncommercial species.

Salvable dead trees.—Standing or down dead trees, that are considered currently or potentially merchantable by regional standards.

Saplings.—Live trees of commercial species 1.0 to 5.0 inches in diameter at breast height and of good form and vigor.

Saw log.—A log meeting minimum approved log-grade specifications, or for species for which approved log grades are lacking; at least 12 feet long if conifer or 8 feet long if hardwood, with a minimum d.i.b. of 6 inches, and with deduction for defect no greater than two-thirds the gross volume.

Sawtimber stands.—Stands at least 10 percent stocked with growing-stock trees, with half or more of this stocking in sawtimber and poletimber trees and with sawtimber at least equal to poletimber stocking.

Sawtimber trees.—Live trees containing at least one minimum saw log. Softwoods must be at least 9.0 inches in diameter at breast height, except in California, Oregon, Washington, and coastal Alaska where the minimum diameter is 11.0 inches. Hardwoods must be at least 11.0 inches in diameter in all States.

Seedlings.—Established live trees of commercial species less than 1.0 inch in diameter at breast height and of good form and vigor.

Softwoods.—Coniferous trees, usually evergreen, having needles or scalelike leaves.

Stand-size class.—A classification of forest land based on the predominant size of timber present; that is, sawtimber, poletimber, or saplings and seedlings.

State, county, and municipal lands.—Lands owned by States, counties, and local public agencies, or lands leased by these government units for 50 years or more.

Standard Industrial Classification (SIC).—A classification of establishments by type of activity in which engaged. An "establishment" is an economic unit which produces goods or services.

Stocking.—A measure of the degree which area is occupied or utilized by trees of specified classes, including (1) all live trees, (2) growing-stock trees, and (3) desirable trees. Classification of forest land and forest types is based on stocking of all live trees. Stocking of growing-stock trees is used to determine stand size and age class.

Stocking standards.—The minimum number of well-spaced trees required to fully utilize the area by specified forest types and sites.

Timber cut from sawtimber.—The net board-foot volume of live sawtimber trees cut for forest products during a specified period, including both roundwood products and logging residues.

Timber products.—Roundwood products and byproducts of primary wood manufacturing plants. Includes saw logs, veneer logs and bolts, cooperage logs and bolts, pulpwood, fuelwood, piling, poles, posts, hewn ties, mine timbers, and other round, split, or hewn products.

Timber products industries.—Industries included in Major Group 24, Lumber and Wood Products, Except Furniture, and Major Group 26, Paper and Allied Products, described in the Standard Industrial Classification Manual. The major industries are:

Logging.—Logging camps and logging contractors primarily engaged in cutting timber and in producing rough, round primary forest or wood raw materials.

Sawmills and planing mills.—Establishments primarily engaged in sawing rough lumber and timber from logs and bolts, or resawing cants and flitches into lumber, including box lumber, and softwood cut stock; planing mills combined with sawmills; and separately operated planing mills which are engaged primarily in producing surfaced lumber and standard workings or patterns lumber.

Veneer and plywood plants.—Establishments primarily engaged in producing commercial veneer, either face or technical, and those primarily engaged in manufacturing commercial plywood, including nonwood backed or faced veneer and nonwood faced plywood, from veneer produced in the same establishment or from purchased veneer.

Paper and allied products.—Establishments primarily engaged in the manufacturing of pulps from wood and other cellulose fibers and rags; the manufacture of paper and paperboard; and the manufacture of paper and paperboard into converted products such as paper coated off the paper machine, paper bags, paper boxes, and envelopes.

Miscellaneous wood manufacturing.—Employment reported for several other SIC divisions within Major Group 24 were combined as miscellaneous wood manufacturing. The group includes hardwood dimension mills, shingle mills, millwork plants, prefabricated structures, wooden containers, and wood preserving. Industries in this group are either secondary manufacturers or they process a small amount of the total log harvest. They employ a relatively small proportion of the total number of workers.

Wood is consumed by firms in Major Group 25, Furniture and Fixtures, but these industries were not studied because the quantities of wood processed, often in combination with other materials, and number of workers employed in the Pacific Northwest are small.

Unproductive forest land.—Forest land incapable of yielding crops of industrial wood because of adverse site conditions. Includes sterile or poorly drained forest land, subalpine forests, and steep rocky areas where topographic conditions are likely to prevent management for timber production.

Volume of growing stock.—The cubic-foot volume of sound wood in the bole of noncull sawtimber and poletimber trees of commercial species from a 1-foot stump to a minimum 4.0-inch top outside bark or to the point where the central stem breaks into limbs.

Volume of sawtimber.—Net volume of the saw-log portion of live sawtimber trees in board feet.

Wall, Brian R.
1969. Projected developments of the timber economy of the Columbia-North Pacific Region. U.S.D.A. Forest Service Res. Pap. PNW-84, 87 pp. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

This report examines the present forest resource and forest industry in the Columbia-North Pacific Region of Washington, Oregon, Idaho, western Montana, and Teton County, Wyoming. Projections of the future timber economy have been made for industry and subregions to the year 2020. The mix of forest industries is projected to change, resulting in decreasing wood consumption by the lumber industry and increasing wood consumption by the veneer, plywood, and pulp and paper industries. Forest industrial employment will decline as worker productivity increases. Payrolls in the forest industries are projected to increase, reflecting gains in productivity and the continuing demands for skilled labor.

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Wall, Brian R.
1969. Projected developments of the timber economy of the Columbia-North Pacific Region. U.S.D.A. Forest Service Res. Pap. PNW-84, 87 pp. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

This report examines the present forest resource and forest industry in the Columbia-North Pacific Region of Washington, Oregon, Idaho, western Montana, and Teton County, Wyoming. Projections of the future timber economy have been made for industry and subregions to the year 2020. The mix of forest industries is projected to change, resulting in decreasing wood consumption by the lumber industry and increasing wood consumption by the veneer, plywood, and pulp and paper industries. Forest industrial employment will decline as worker productivity increases. Payrolls in the forest industries are projected to increase, reflecting gains in productivity and the continuing demands for skilled labor.

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DOUGLAS-FIR BARK TANNIN DECOMPOSITION IN TWO FOREST SOILS

W. B. BOLLEN • K. C. LU

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INTRODUCTION

About 5 million tons of tree bark are produced annually as waste from wood-using industries in the Pacific States. Douglas-fir is the principal species involved. Most of this bark is burned, a practice which contributes significantly to air pollution in areas of mill concentration. Alternative methods of disposing of tree bark include agricultural or horticulturai use as mulches or soil conditioners. Another possibility is to debark trees at the logging site and return the bark to the soil for stabilization and organic matter maintenance.

Known effects of adding bark to soil have been summarized (Bollen 1969),[1/] but one aspect of the problem has not hitherto been closely examined--the effect of bark tannins on the soil.

Tree barks contain various amounts of tannins, water soluble polyphenols capable of forming complexes with proteins and other organic substances. Douglas-fir bark contains from 5 to 22 percent tannin by weight (table 1), depending on tree age and section of the stem from which the bark came (Kurth et al. 1948). Bark has been applied to soil at rates of up to 100 tons per acre, so as much as 20 tons per acre (20,000 parts per million (p. p. m.) per acre 2 million pounds of soil) of tannins might thus be added. Bark residues on forest and cut-over lands also add tannins.

To answer questions concerning the fate of these bark tannins in soil and their effect on the soil, we posed these questions: (1) How rapidly do tannins decompose in soil? (2) Do they affect microbial populations and accumulation of nitrate nitrogen at a concentration possible from common applications of bark mulches and incorporations in agriculture?

Barks of other western tree species also contain tannins in amounts sufficient to require consideration when bark is added to soil (table 1).

REVIEW of PREVIOUS RESEARCH

Certain plant pathogenic fungi are inhibited and finally killed by tannin added to culture media, but saprophytic fungi are less sensitive (Cook 1911). *Aspergillus niger*, a common soil mold, can thrive on tannin and has been used commercially to hydrolyze tannin to gallic acid (Prescott and Dunn 1959). Koch and Oelsner (1916) reported that tannin is readily assimilated by soil molds. Certain cellulolytic bacteria are inhibited by tannins at 100 to 1,000 p. p. m., but growth

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[1/] Names and dates in parentheses refer to Literature Cited, p. 10.

Table 1.--*Tannin in bark of some Pacific Northwest tree species*

Species	Bark tannin	Reference
	Percent	
Douglas-fir *(Pseudotsuga menziesii)*	8-18	Kurth (1953)
	5-22	Hathway (1960)
Western hemlock *(Tsuga heterophylla)*	15-16	Howes (1953)
Sitka spruce *(Picea sitchensis)*	11-37	Frey and Clarke (1941)
Ponderosa pine *(Pinus ponderosa)*	6-11	Kurth and Hubbard (1951)
Sugar pine *(Pinus lambertiana)*	5-7	Kurth et al. (1949)
Western larch *(Larix occidentalis)*	16	Jarvis (1959)
Western redcedar *(Thuja plicata)*	5-7	Smith and Kurth (1953)
Incense-cedar *(Libocedrus decurrens)*	4-8	Smith and Kurth (1953)
Redwood *(Sequoia sempervirens)*	1-3	Wilson and Thomas (1927)
	2-8	Gnamm (1949)
Port-Orford-cedar *(Chamaecyparis lawsoniana)*	4-7	Smith and Kurth (1953)
Mountain hemlock *(Tsuga mertensiana)*	16-21	Kurth (1958)
Red alder *(Alnus rubra)*	4	Kurth and Becker (1953)
Grand fir *(Abies grandis)*	7	Kurth and Tokos (1953)
Red fir *(Abies magnifica)*	16	Becker and Kurth (1958)
White fir *(Abies concolor)*	6-10	Hergert and Kurth (1953)

of others, except for changes in morphology, is only slightly affected (Henin, Tagari, and Volcani 1964). Shrikhande (1940) showed that fermentation of tea refuse was not impeded by the tannin complex, but its decomposition was qualitatively altered by selective action on the microflora.

Douglas-fir bark decomposes in soil more slowly than sawdust. The bark bast is more resistant than the cork fraction (Allison 1965; Bollen and Glennie 1961), which contains tannins, dihydroquercitin, and other more or less toxic extractives. Aspitarte[2/] treated Willamette silty clay loam soil with Douglas-fir tannin liquor equivalent to 2,000 p.p.m. carbon and found 33 percent of the tannin was decomposed in 60 days.

Basaraba and Starkey (1966), using carbon dioxide evolution as an index, showed that tannins combine with proteins and reduce the rate of decomposition of the complexes in liquid media inoculated with soil. However, chestnut *(Castanea dentata)* and wattle *(Acacia* spp.) tannins alone decomposed more slowly than the tannin-protein complexes.

Benoit, Starkey, and Basaraba (1968) found that wattle tannin reduced decomposition of whole plant materials about 50 percent in inoculated culture media having pH values of 4.0 and 7.0. Although protein-tannin complexes were resistant, the effect of tannin on the whole-plant materials was not correlated with their nitrogen content and was, therefore, believed due to causes other than the formation of complexes with plant proteins. Benoit and Starkey (1968) found that tannin reduces activity of cellulase and other exoenzymes of micro-organisms involved in decomposing organic compounds of large molecular weight, such as cellulose and proteins. They concluded that reduction of the exoenzyme activity is an important factor in the inhibitory effect of tannins on decomposition of plant residues. Tannins thus may influence the accumulation of organic matter, particularly in forest soils, and may also promote persistence of organic matter in other soils to which bark is applied.

Lewis and Starkey (1968) found that, in a hardwood forest soil, the hydrolyzable tannins, tannic acid, gallotannin, and chestnut tannin, as well as the simple tannin, catechin, underwent appreciable decomposition in 60 days as indicated by CO_2 evolution. Only a little CO_2 was released from tannins of wattle and canaigre *(Rumex hymenosepalus)*. Resistance of tannin-protein complexes to decomposition varied with the tannins and proteins. The tannins also retarded decomposition of starch, chitin, saponin, and, to a lesser degree, pectin.

MATERIALS AND METHODS

Douglas-fir bark was first treated sequentially with hexane, benzene, ether, and 95 percent ethanol[3/] to remove waxes, flavonoids, and phlobophenes. After

[2/] Aspitarte, T. R. Availability of nitrogen in ammoniated bark used as a soil amendment. 1959. (Unpublished Ph.D. thesis on file at Oreg. State Univ., Corvallis.)

[3/] By Dr. Harvey Aft, Forest Research Laboratory, Oregon State Univ., Corvallis.

this initial treatment, tannin was extracted from the bark with hot water. The dried extract contained 97 percent tannin and about 0.1 percent sugars. Analysis of the powdered extract gave the following results (percent): water 8.33; ash 2.07; carbon 55.69; nitrogen 0.12. The ash and nitrogen are extraneous, representing unavoidable natural contaminations of bark on the tree.

Two forest soils differing widely in organic matter content and microbial populations (table 2) were used. One, the A1 horizon of an Astoria-like silty clay loam hereafter referred to as "Astoria soil," was collected beneath a 40-year-old stand of mixed Douglas-fir, western hemlock, and Sitka spruce. The other was the C horizon of Preacher clay loam, beneath a Douglas-fir-western hemlock forest. The soils were air-dried and passed through a 10-mesh screen before use.

Two-hundred-gram portions, ovendry basis, of each soil were treated in triplicate as follows: (1) soil only; (2) soil plus dextrose equivalent to 2,000 p.p.m. carbon; and (3) soil plus the purified tannin equivalent to 2,000 p.p.m. carbon or 3,775 p.p.m. (0.38 percent) tannin. This tannin addition approximates the amount of tannin leachable from a 2-inch bark mulch, if we assume a tannin content of 10 percent. A mulch this deep, common in actual use, weighs 20 tons per acre, ovendry basis. The actual amount of tannin leached and its concentration in the underlying soil will vary with the amount and timing of precipitation or irrigation and with depth of penetration of water into the soil.

Microbial populations, nitrate content, and nitrification were determined by methods of Bollen et al. (1967). Carbon dioxide evolution was determined according to Bollen and Lu (1957).

RESULTS AND DISCUSSION

TANNIN DECOMPOSITION

Decomposition of native soil organic matter, tannin, and dextrose was measured as the amount of CO_2 evolved during incubation (Bollen and Lu 1957). Dextrose, a readily available source of carbon, served as a standard for comparison with other treatments because it is rapidly decomposed by microbes.

Native organic matter, dextrose, and tannin all decomposed at a greater rate in the highly organic Astoria soil than in the Preacher soil of very low organic matter content (fig. 1). Part of the CO_2 which evolved from soils to which tannin or dextrose had been added may have come from native soil organic matter. When a carbonaceous substance is added to soil, the heterotrophic microflora population is stimulated and microbial attack on native soil constituents increases (Hallam and Bartholomew 1953); this is the "priming effect" discussed by Starkey (1968). We show "apparent decomposition" in figure 1 to best indicate the real amount of tannin and dextrose decomposed. Apparent decomposition is expressed as the percentage of carbon evolved as CO_2 from native and added organic matter in treated soil less that given off by untreated soil.

Table 2.--*Chemical and physical properties of Astoria and Preacher soils*[1/]

Chemical properties	Astoria clay loam (A1 horizon)	Preacher loam (C horizon)
Total carbon (percent)	14.48	0.24
Nitrogen (p.p.m.[2/]):		
NH_4^+	17.00	.00
NO_2^-	.10	.00
NO_3^-	21.00	1.1
Kjeldahl[3/]	7,400.00	200
Carbon: nitrogen ratio	19.00	12
pH	5.30	4.6
Total cation exchange capacity (meq. per 100 g.[4/]):	69.0	19.1
Exchangeable H^+	30.4	16.7
Exchangeable Ca^{++}	12.5	1.7
Exchangeable Mg^{++}	16.0	.4
Exchangeable K^+	5.2	.3
Sum of cations	64.1	19.1
Available phosphorus (p.p.m.)	4.30	3.0
Physical properties:	- - - - - - - - *Percent* - - - - - - - -	
Water-holding capacity	206	57
Water retention at:		
0.1 atmosphere	79.84	42.6
0.33 atmosphere	58.15	33.1
1.0 atmosphere	44.69	25.3
15.0 atmospheres	31.14	14.8
Mechanical analysis:		
Sand	28.9	42.35
Silt	47.1	39.64
Clay	23.9	18.01

1/ Analytical methods are described in Bollen et al. (1967).

2/ Parts per million.

3/ Includes NO_2^--N and NO_3^--N.

4/ Milliequivalents per 100 grams.

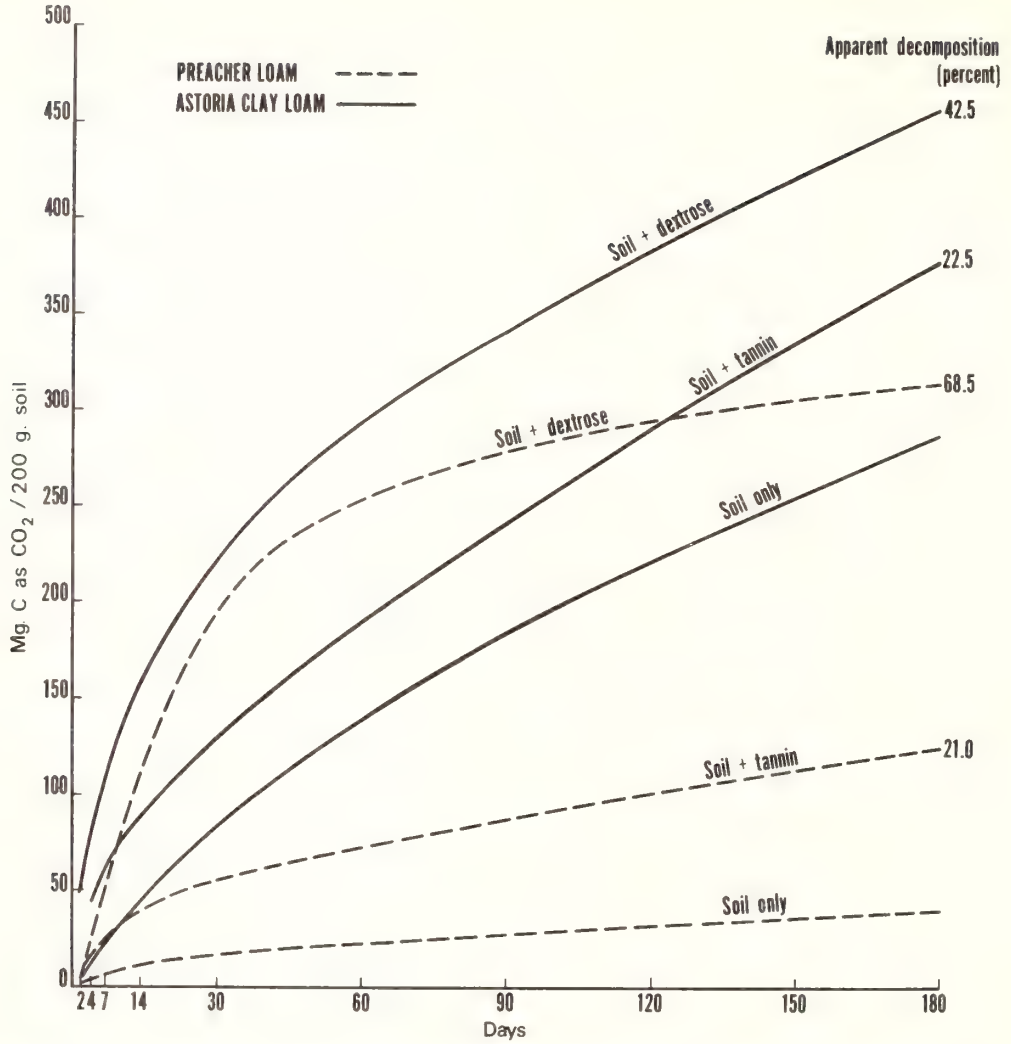

Figure 1.--Influence of Douglas-fir bark tannin and dextrose on CO_2 production. Preacher loam, and Astoria clay loam.

Total CO_2 evolution from Astoria soil plus dextrose was much higher than that from Preacher soil plus dextrose. However, untreated Preacher soil produced much less CO_2 than did the untreated Astoria soil, so apparent decomposition of dextrose in the Preacher soil was much higher, 68.5 percent, than in Astoria soil (42.5 percent). Total evolution of CO_2 from soil to which tannin had been added was also much greater in Astoria than in Preacher soil, but again the higher CO_2 production by Astoria soil alone compensated, in this case resulting in an apparent decomposition of tannin at about the same level in both soils--nearly 22 percent.

At least two additional factors further lessen the impact of tannin on soil properties. From 2 to 5 percent of bark residues from lumber mills is wood particles, the tannin content of which is negligible. In addition, bark contains an abundant microbial population which undoubtedly decomposes some of the tannin before it can leach into the soil.

MICROBIAL POPULATIONS

Koch and Oelsner's (1916) report that adding tannin to soil greatly favors development of molds is supported by our findings (table 3). Incubation of untreated soil substantially increased numbers of molds in both soils studied, but incubation of soil to which tannin was added further increased their numbers by 10 times in Astoria and 25 times in Preacher soil (table 3).

Some changes in predominant kinds of molds were also noted. In the Preacher soil alone, incubation increased *Penicillium* percentage, but incubation with tannin caused no further change in proportions. In the Astoria soil, incubation decreased percent of *Penicillium*, but incubation plus tannin caused a predominance of this species of mold. Other mold colonies, not identified, were almost exclusively compact, white, and sterile.

Table 3.--*Microbial populations in soil--unincubated, incubated, and incubated with tannin treatment*

(Means of three replications)

Treatment and days incubated	Molds		Bacteria	
	Total	*Penicillium*	Total	*Streptomyces*
	Thousands per gram	Percent	Millions per gram	Percent
PREACHER LOAM				
Soil alone (0)	3	68	0.05	34
Soil alone (180)	43	94	2.00	0
Soil+tannin[1/] (180)	1,073	98	4.80	2
ASTORIA CLAY LOAM				
Soil alone (0)	195	39	9.30	45
Soil alone (180)	240	23	20.90	69
Soil+tannin[1/] (180)	2,472	93	42.20	92

[1/] Tannin was added at the equivalent of 2,000 p.p.m. carbon.

Bacterial population was also affected by the treatments, but not so strikingly as were molds. Incubation markedly increased numbers of bacteria, especially in the Preacher soil, and incubation plus tannin caused a further doubling. *Streptomyces* spp. were eliminated in incubated Preacher soil and also, to a large extent, in the incubated tannin-treated soil. In Astoria soil, on the other hand, incubation increased percentage of *Streptomyces* and incubation of tannin-treated soil resulted in an even greater preponderance of these higher bacteria.

It should be noted that bark carries a high microbial population (Bollen 1969) which undoubtedly decomposes some of the tannin before it can be leached into the soil. Thus, in a bark mulch, the same initial level of tannin as that used in our experiment would likely affect soil microbial activities less than did the extracted tannin concentration we used.

NITRIFICATION AND NITRATE PRODUCTION

In the low-nitrogen Preacher soil, nitrates in untreated samples increased from an initial 1.1 p.p.m. to 1.5 p.p.m. after incubation (table 4). However, the nitrate level in incubated soil to which tannin had been added was only 1.3 p.p.m. Results of nitrification studies with the Astoria soil were of greater magnitude because of higher beginning nitrogen content, and the decreases due to to tannin addition were more pronounced. In this case, a definite, though not extensive, retardation of nitrification occurred.

In some areas increases in nitrate production after timber harvesting have been shown to pose a hazard to stream water quality. Bormann et al. (1968) found nitrate concentrations in a small stream draining a cutover ecosystem to have exceeded established pollution levels (10 p.p.m.) for more than 1 year after cutting, and algal blooms appeared during the summer period. Bollen (1969) suggested that tree bark might best be left on the forest soil after timber harvesting to provide physical protection against soil erosion, to allow some return of organic matter and mineral nutrient elements to the soil, and especially to aid in reducing undesirable buildup of leachable nitrates. Evidence from our study of tannin effects on nitrification appears to further support the desirability of leaving as much bark on the cutting area as possible in order to slow nitrification and thus reduce excessive formation of water-polluting nitrates.

SUMMARY

Addition of tannin to two greatly different forest soils produced no evident harmful effects. However, the moderate decrease in nitrification effected by tannin bears consideration in agricultural use. This feature could even be useful in watershed management because leaving bark on forest soils may lower nitrate production and thus decrease the hazard of nitrates in water supplies fed by forest streams.

Table 4.--*Nitrification of native organic matter and added tannin after incubating two soils*

(Means of three replications)

Treatment and days incubated	NO_2-N	NO_3-N	Net NO_2-N plus NO_3-N after incubation
		P.p.m.	
PREACHER LOAM			
Soil alone (0)	0	1.1	--
Soil alone (180):			
Gross	.02	1.5	--
Net	.02	.4	0.42
Soil+tannin[1/] (180):			
Gross	.10	1.3	--
Net	.10	.2	.30
ASTORIA CLAY LOAM			
Soil alone (0)	.10	21.0	--
Soil alone (180):			
Gross	.60	86.0	--
Net	.50	65.0	65.50
Soil+tannin[1/] (180):			
Gross	.10	77.0	--
Net	.00	56.0	56.00

[1/] Tannin was added at the equivalent of 2,000 p.p.m. carbon.

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Purified Douglas-fir bark tannin equivalent to the amount in a 2-inch bark mulch was added to two widely different soils in the laboratory. About 22 percent of the tannin decomposed in 180 days. Soil microflora generally increased. Nitrate production was slightly decreased in the presence of tannins. Douglas-fir bark added to soil appears harmless from the standpoint of its tannin content.

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LODGEPOLE PINE CLEARCUT
SIZE AFFECTS MINIMUM TEMPERATURES NEAR THE SOIL SURFACE

by P. H. Cochran

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE · PORTLAND, OREGON
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INTRODUCTION

Large openings in several-aged lodgepole pine (*Pinus contorta* Dougl.) stands on flat topography in the pumice soil region of south-central Oregon are often hard to regenerate. As an example, a 7.4-acre clearcut, made in this type of lodgepole stand in 1938 on the Pringle Falls Experimental Forest, has not regenerated and seedling establishment in the opening has been restricted to a narrow area adjacent to the stand edge. Many other such cases occur within approximately one-half million acres of lodgepole pine growing on the Deschutes, Winema, and Fremont National Forests.

There are several possible reasons for this regeneration problem. Animal damage to seedlings may be an important factor. Many types of small animals, especially pocket gophers (*Thomomys talpoides*), tend to congregate and feed in these openings.

Seed dispersal can be inadequate. Lodgepole pine cones in this region open and shed their seed promptly following ripening, and there are adequate seed crops in at least 3 out of every 4 years. However, the number of seeds dispersed into clearcut areas falls off rapidly as distance from the stand edge increases and reaches a very low level at distances beyond 3 chains.[1/]

Heat injury and drought may cause some mortality. Lodgepole pine seedlings are abundant in many clearcuts on undulating or slightly sloping topography. In these situations, cold air has less tendency to accumulate at night than it does on flat areas, which suggests that low rather than high temperatures near the soil surface hinder lodgepole pine establishment in pumice soils.

Frost heaving, also a problem in parts of the pumice soil region, appears to cause the most damage in areas where amounts and patterns of snow accumulation create bare areas between drifts in the early spring.

In addition to the foregoing factors, severe night frosts during germination may be a significant cause of lodgepole pine seedling mortality. Berntsen[2/] found in laboratory experiments that lodgepole pine seedlings were killed during their germination period by night minimum temperatures of 13° F. (-10.6° C.). Field observations indicate several-aged lodgepole stands are naturally perpetuated by regeneration of small openings created by mortality of small groups of trees or single old trees. The plentiful natural regeneration in these small, partially protected openings and the lack of natural regeneration at distances greater than about 1 chain (one tree height) from the stand edge in several large clearcuts further indicate that low temperature may be a cause of regeneration problems.

Low night temperatures are common during the growing season in the pumice soil region of Oregon. Near Chemult, Oregon, the likelihood of

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[1] *Dahms, Walter G. Dispersal of lodgepole pine seed into clearcut patches. Pacific Northwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Res. Note PNW-3, 7 pp., illus. 1963.*

[2] *Berntsen, Carl Martin. Relative low temperature tolerance of lodgepole and ponderosa pine seedlings. 158 numb. leaves. 1967. (Unpublished Ph.D. thesis on file at Oregon State Univ., Corvallis.)*

frost is greater than 50 percent on any summer night.[3] At least four factors contribute to this high frequency of night frost: (1) high altitude, (2) preponderance of clear nights, (3) a relatively dry airmass, and (4) the unique thermal properties of pumice soils. Pumice soils have much lower thermal diffusivities and much lower thermal contact coefficients at comparable water contents than other mineral soils of greater density, so wide surface temperature variations may be expected.[4] Thermal properties of pumice soils closely resemble those of peat soils on which frost hazards to crops have long been recognized.[5]

Lodgepole pine stands are commonly harvested by the strip clearcut method. If low temperatures are a problem in lodgepole pine regeneration, it is important to know how width of the cutting strip affects minimum temperatures near the soil surface.

MATERIALS AND METHODS

On a clear night, the open soil surface radiates more energy outward toward the sky in the form of long-wave radiation than the sky radiates downward. The resulting net loss of energy causes the soil surface to cool rapidly, and very low minimum surface temperatures become possible. The net radiation flux for any particular spot on the soil surface within a forest opening during a clear, windless night is determined largely by the relative amount of radiation it receives from a "cold" sky and a "warm" tree canopy. This proportion can be represented by a geometric concept called the view factor.

The view factor is the fraction of radiation leaving a surface in all directions that is intercepted by another surface.[6] Of concern here is the view factor of a spot on a horizontal surface relative to the open sky. The greater the view factor for a particular spot, the more closely the net radiation flux of that spot will resemble the net radiation flux of a similar surface in a completely open area under the same meteorological conditions.

View factors were calculated for circular openings of various widths and for rectangular openings of various lengths and widths. View factors were also calculated for spots at various distances from the stand edge for very large clearcuts where the spots were influenced by only one stand edge. The equations used in these calculations and their derivations are given in the Appendix.

Minimum temperatures at 2.5 inches above the soil surface were determined at various distances from the edge of a clearcut in a several-aged lodgepole pine stand growing on flat topography on a Lapine pumice soil. Stand height is approximately 62 feet. The dimensions of the rectangular clearcut are

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[3] *Eichorn, N. D., Rudd, R. D., and Calvin, L. D. Estimating dates for low temperatures in Oregon, Corvallis. Oregon Agr. Exp. Sta. Bull. 581, 16 pp. 1961.*

[4] *Cochran, P. H., Boersma, L., and Youngberg, C. T. Thermal properties of a pumice soil. Soil Sci. Soc. Amer. Proc. 31:454-459. 1967.*

[5] *Wijk, W. R. van. Soil microclimate, its creation and modification. Meteorol. Monogr. 6(28):59-73, illus. 1965.*

[6] *Reifsnyder, William E., and Lull, Howard W. Radiant energy in relation to forests. U.S. Dep. Agr. Tech. Bull. 1344, 111 pp., illus. 1965.*

4.5 by 17.4 chains, with the long axis of the opening oriented in a north-south direction. The cut was made in 1938 and the soil surface in the opening is sparsely covered with grass; stumps, logs, and logging debris have largely disappeared. Temperatures were measured at the stand edge, 50 feet into the stand, and 50, 75, and 120 feet from the east edge of the stand in the opening. The measurement points were located on a transect perpendicular to the long axis of the opening.

Measurements were recorded with a data-logging system described elsewhere.[7] Thermistors were used as temperature sensors. Each thermistor was encased in a piece of polyvinyl chloride tubing which had been previously stretched in methyl-ethyl-ketone. After the tubing had shrunk around the thermistor, the assembly was dipped in epoxy resin to make a waterproof seal. The thermistor covering was then sprayed with white paint. The thermistors plus covering were approximately 1 cm. long and 0.25 cm. in diameter and had a resistance of 3,000 ohms at 25° C. with a tolerance of ± 1 percent. The thermistors were held at 2.5 inches above the soil surface by lead wires taped to the ends of L-shaped wires inserted into the ground.

Records were taken every 2 hours for periods of 1 to 2 days at approximately weekly intervals from May 30 to September 26, 1968. Recorders were started so that thermistor inputs were sensed just before sunrise to obtain minimum temperatures for the day. Hygrothermograph readings taken 2 miles from the study area indicated that minimum temperatures did occur just before sunrise for the days temperatures were recorded at the clearcut.

RESULTS AND DISCUSSION

View factors for circular openings are less than for strips of the same width (fig. 1). Thus, circular openings offer more protection against low soil-surface temperatures than long strips

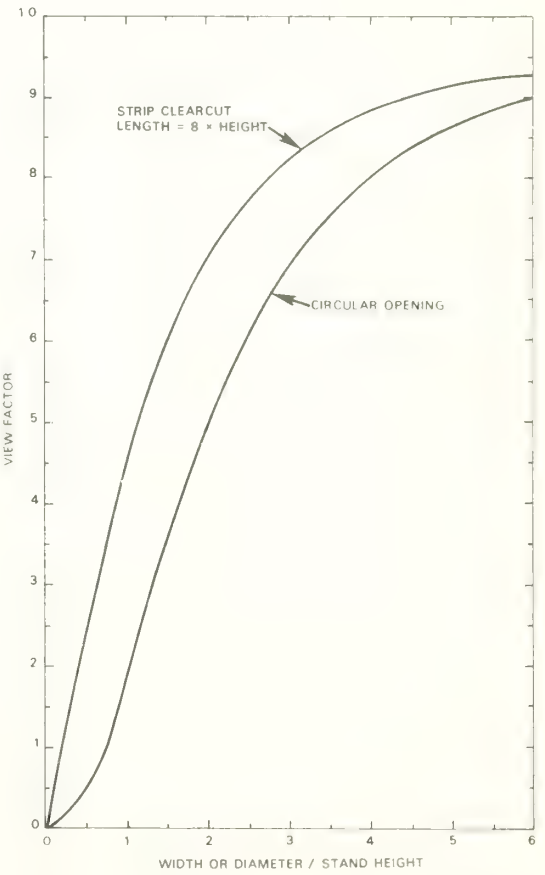

Figure 1.—View factor for the center of a rectangular and a circular forest opening as a function of opening width divided by stand height.

[7] *Cochran, Patrick Holmes. Heat and moisture transfer in a pumice soil. 165 numb. leaves. 1966. (Unpublished Ph.D. thesis on file at Oregon State Univ., Corvallis.)*

of the same width. On cold, clear, windless nights, when the sky has a lower effective temperature than the tree canopy, surface temperatures in strips will become lower than in circular openings of the same width. The soil surface in the center of the strip receives more radiation from the "cold" sky and less radiation from the "warm" tree canopy than does the center surface of the circular opening.

The view factor for the center of a long strip[8]--which is 4.5 times as wide as the stand height--is 0.9, indicating that the strip center is practically in the open. The view factor for the center of the circular opening does not reach 0.9 until the opening has a diameter 6 times the stand height. The low view factors for circular openings may explain why small, natural, circular openings in lodgepole pine stands usually have abundant natural regeneration, even when the stands are several aged on flat or depressional topography.

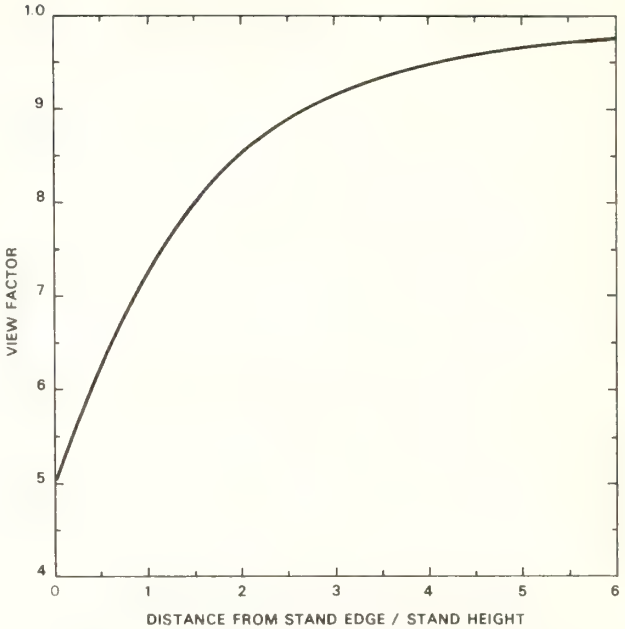

Figure 2.—View factor for spots on the soil surface in a very large rectangular opening as a function of distance from the stand edge divided by stand height.

Circular clearcuts are not practical in lodgepole pine management because small, irregularly shaped patches of timber would be created. These patches would eventually have to be logged and this operation would be inefficient. Therefore, strip or block clearcuts are employed. For large clearcuts, the protective influence of the stand edge tapers off rapidly with distance into the opening. For example, at a distance outward from the stand edge equal to stand height, the view factor is above 0.7 (fig. 2). At a distance outward equal to 3 times the stand height, the view factor is above 0.9. The minimum temperature averages also indicate that minimum temperatures decrease rapidly over a short distance outward from the stand edge (fig. 3). The data in figure 3 were taken after the germination period. During the germination period, the same pattern but lower temperatures may be expected. This minimum temperature pattern provides a possible explanation for the confinement of natural regeneration in some large clearcuts to outward distances approximately equal to stand height. Seed dispersal is adequate to greater distances,[9] so the absence of seedlings between 1 and 3 chains from the stand edge is not due to lack of seed.

Long clearcuts, wider than 4 to 6 times stand height, create essentially

[8] *A long strip here is used to indicate any strip with a length greater than 8 times the height of the stand. For strips of any given width, the view factor for the strip center is not appreciably increased by increasing strip length beyond 8 times stand height.*

[9] *See footnote 1.*

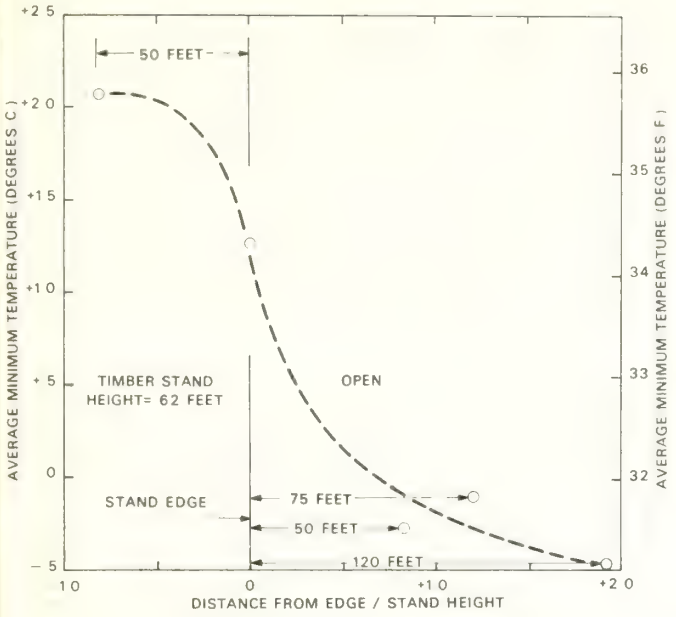

Figure 3.—Average minimum air temperatures at 2.5 inches above the soil surface for 18 days in a period starting May 30 and ending August 30, 1968. The dashed line is a freehand curve.

open areas toward the center of the strip. The moderating effect of the stand on minimum temperatures is insufficient to provide protection clear across the strip. Although the amount of protection necessary for lodgepole pine regeneration is not known, observations indicate a view factor of 0.7 or greater may result in minimum temperatures which are too low for newly germinated tree seedlings in problem areas. A problem area is regarded here as a several-aged lodgepole pine stand occurring on flat or depressional pumice-mantled topography. If this assumption is correct, prompt natural regeneration cannot be expected beyond a distance equivalent to tree height from the timbered edge in certain problem areas when widths of long strip clearcuts exceed three tree heights.

If natural regeneration is to be obtained in these problem areas, strip clearcuts should not be wider than twice the height of the stand. When other factors such as mistletoe control dictate that cutting strips in these problem areas must be wider than two tree heights, the center of the strip should be planted.

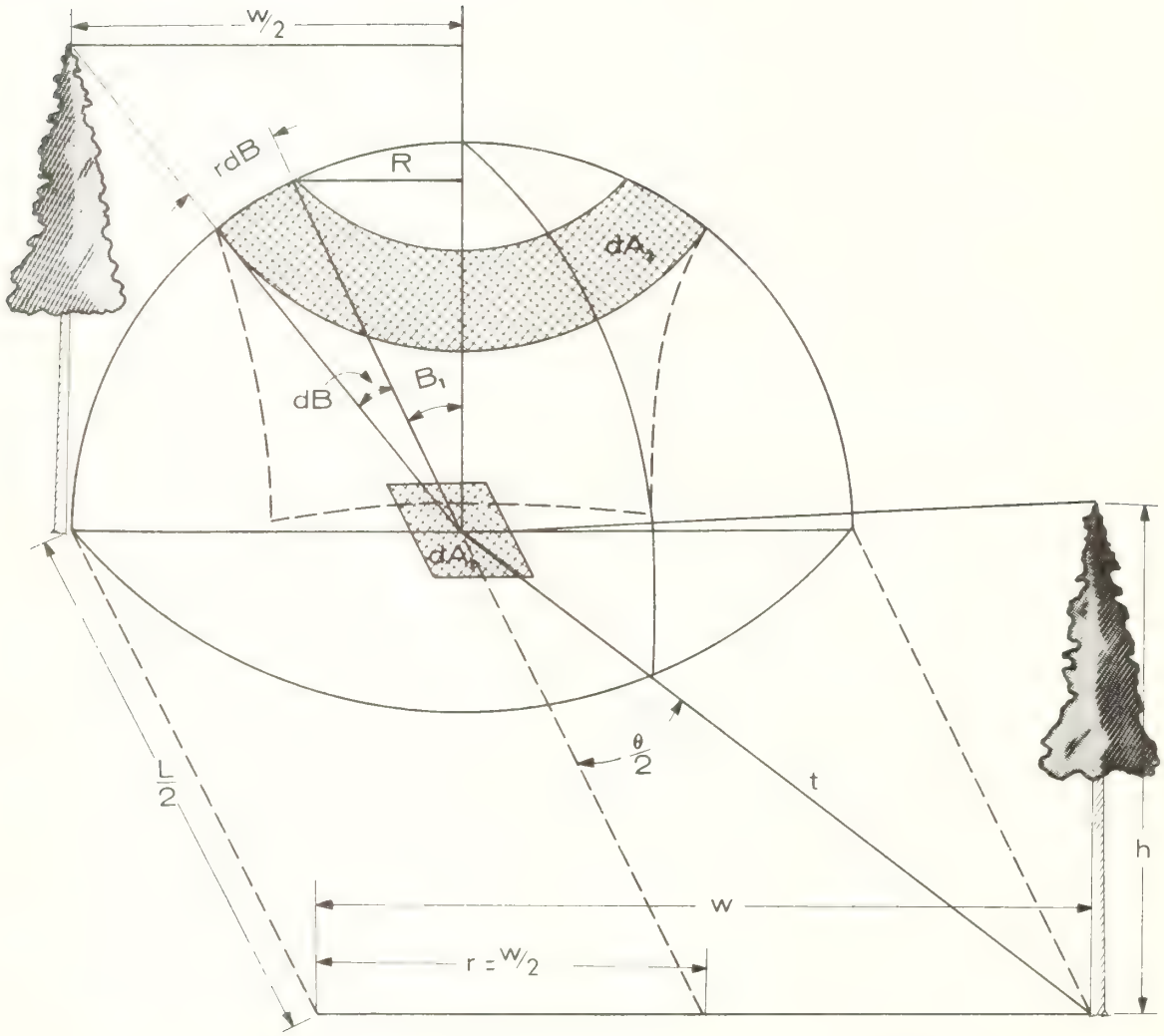

Figure 4.—Diagram used in the derivation of view factors for circular and rectangular forest openings. Area enclosed by dashed line represents that portion of the hemisphere open to the sky for a rectangular opening.

APPENDIX

Derivation of the view factor for a rectangular forest opening was accomplished by modification of and addition to the derivation of the view factor for a circular opening, presented by Reifsnyder and Lull (see footnote 6).

Consider an opening in tne forest of width (w) and length (L) surrounded by trees of height (h) (fig. 4). The sky above a small area, dA_1, in the center of the opening subtends a solid angle corresponding to arc tan ($w/2h$). A ray from dA_1 to the partial hemisphere of sky makes an angle, B_1, with the normal to dA_1 This ray meets the hemisphere at 90° angle. Therefore, B_2, the angle between the ray and the normal to the hemisphere at the point of intersection is 0°. The amount of radiation, dW, leaving dA_1 in the direction B_1 and intercepted by the surrounding hemisphere, is (see footnote 6):

$$dW_{1\to 2\ (\text{sky})} = \frac{I_1 dA_1 \cos B_1 dA_2 \cos B_2}{r^2} \tag{1}$$

I_1 is the radiant flux density at dA_1 and $r = w/2$. The differential ring or ring segment, dA_2, is (see figure 4)

$$dA_2 = N\ RrdB$$

where N varies from 2π to 4 arc tan (w/L). Since cos $B_2 = 1$, and $R/r = \sin B_1$, equation 1 becomes

$$dW_{1\to 2\ (\text{sky})} = NI_1 dA_1 \sin B_1 \cos B_1 dB \tag{2}$$

For that portion of the hemisphere above the lower boundary of dA_2 as drawn in the figure, $N = 2\pi$ and B_1 varies from $B_1 = 0$ to arc tan ($w/2h$). Integrating over this interval,

$$W_{1\to 2\ (\text{sky})} = 2\pi\ I_1 dA_1 \int_0^{\text{arc tan } (w/2h)} \sin B_1 \cos B_1\ dB \tag{3}$$

$$= \pi\ I_1 dA_1\ \sin^2 \left[\text{arc tan } (w/2h)\right] \tag{4}$$

For that portion of the hemisphere below the lower boundary of dA_2 as drawn in figure 1A, $N=2\ \theta$ where θ is the angle between lines of sight from the center of dA_1 to the base of two trees directly opposite one another along the sides of the strip. Also, in this same portion of the hemisphere, B_1 is taken to vary from arc tan ($w/2h$) to arc tan ($L/2h$). B_1 actually becomes slightly larger than arc

tan $(L/2h)$ for the line of sight which extends from the center of dA_1 to the tree top at the corner of the rectangular opening. Since the interest here is in strips where L is several times w, the slight error introduced by use of arc tan $(L/2h)$ as the upper limit of B_1 is disregarded. θ varies with B_1 in the following manner:

$$t = h \tan B_1 ,$$

$$\sin \frac{\theta}{2} = \frac{w}{2h \tan B_1} ,$$

and

$$\theta = 2 \arcsin \left(\frac{w}{2h \tan B_1} \right)$$

Thus,

$$N = 2\theta = 4 \arcsin \left(\frac{w}{2h \tan B_1} \right)$$

Substitution of this value for N into equation 2 and integrating over the interval B_1 = arc tan $(w/2h)$ to arc tan $(L/2h)$ yields

$$W_{1\to 2 \text{ (sky)}} = 4I_1 \, dA_1 \int_{\arctan (w/2h)}^{\arctan (L/2h)} \arcsin \left(\frac{w}{2h \tan B_1} \right) \sin B_1 \cos B_1 \, dB \qquad (5)$$

For the entire hemisphere over dA_1,

$$W_{1\to 2}(\text{total}) = 2\pi \, I_1 dA_1 \int_0^{\pi/2} \sin B_1 \cos B_1 \, dB \qquad (6)$$

$$= \pi \, I_1 dA_1 \left[\sin^2 B_1 \right]_0^{\pi/2}$$

$$= \pi \, I_1 dA_1 \qquad (7)$$

The view factor, F_{1-2} of the sky relative to the spot dA_1, is defined as that portion of the total radiation leaving the spot that is directed toward the sky,

$$F_{1-2} = \frac{W_{1\to 2 \text{ (sky)}}}{W_{1\to 2 \text{ (total)}}} \qquad (8)$$

$$= \frac{\pi I_1 dA_1 \sin^2 \left[\text{arc tan } (w/2h)\right]}{\pi I_1 dA_1}$$

$$+ \frac{4 I_1 dA_1}{\pi I_1 dA_1} \int_{\text{arc tan } (w/2h)}^{\text{arc tan } (L/2h)} \text{arc sin}\left(\frac{w}{2h \tan B_1}\right) \sin B_1 \cos B_1 dB \qquad (9)$$

$$= \sin^2 \left[\text{arc tan } \left(\frac{w}{2h}\right)\right] + \frac{4}{\pi} \int_{\text{arc tan } \left(\frac{w}{2h}\right)}^{\text{arc tan } (L/2h)} \text{arc sin } \left(\frac{w}{2h \tan B_1}\right) \sin B_1 \cos B_1 dB \qquad (10)$$

The first term on the right-hand side of equation 10 is the view factor for a circular opening of width or diameter w (Reifsnyder and Lull, see footnote 6). Equation 10 was evaluated with a digital computer for various widths and lengths expressed in multiples of tree height h.

View factors were also calculated for spots at various distances from the stand edge for very large clearcuts where the spots are influenced by only one stand edge. In this case, N in equation 2 varies from 2π to θ^1 where θ^1 equals $2\left(\frac{\theta}{2}\right) + \pi$. B_1 varies from 0 to $\frac{\pi}{2}$ to arc tan $(w/2h)$ and $\frac{\theta}{2}$ can be expressed by arc sin $\left(\frac{w}{2h \tan B_1}\right)$.

Thus,

$$N = \theta^1 = 2 \text{ arc sin}\left(\frac{w}{2h \tan B_1}\right) + \pi$$

and equation 10 becomes

$$F_{1\to 2} = \sin^2 \left[\text{arc tan } \left(\frac{w}{2h}\right)\right] + \frac{2}{\pi} \int_{\text{arc tan } \left(\frac{w}{2h}\right)}^{\pi/2} \left[\text{arc sin } \left(\frac{w}{2h \tan B_1}\right) + \frac{\pi}{2}\right] \sin B_1 \cos B_1 dB \qquad (11)$$

where w equals twice the distance from the stand edge and is expressed as a fraction or a multiple of tree height. Equation 11 was also evaluated with a digital computer.

Cochran, P. H.
1969. Lodgepole pine clearcut size affects minimum temperatures near the soil surface. U.S.D.A. Forest Serv. Res. Pap. PNW-86, 9 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Low night temperatures may hinder the establishment of lodgepole pine seedlings in certain areas within the Oregon pumice soil region. Lodgepole stands in these problem areas are several aged and occur on flat or depressional topography. Sky exposures (view factors) for circular and rectangular openings were calculated, and minimum temperatures at 2.5 in. above the soil surface were determined at various distances from the stand edge for a large rectangular opening. If low night temperatures do limit seedling establishment, strip clearcuts in the problem areas should not be wider than twice the height of the stand. If other factors dictate wider strips in these problem areas, plans should be made to plant the strip centers.

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Potential Production in Thinned Douglas-fir Plantations

BY DAVID BRUCE

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
USDA FOREST SERVICE RESEARCH PAPER PNW-87
PORTLAND, OREGON 1969

INTRODUCTION

More Douglas-fir stands are being placed under some degree of intensive management each year in the Pacific Northwest. This requires considerable investment that might be allocated to other uses. Justification of such investments requires information about potential yields which, unfortunately, is relatively scant because few Northwest stands have been under management as many as 40 years--most early studies imposed thinnings that many American foresters today would consider too infrequent and, perhaps, too late.

A relatively unexploited source of information about potential yields of frequently thinned Douglas-fir plantations is the increasing number of Douglas-fir production tables from foreign countries. These tables are theoretical thinning guides which list periodic statistics on stands after thinning, thinning yields, and their sum, which is total production, for as many as 50 to 80 years. Indicated yields are based on examination of sample plots in 50 to 100 or more thinned plantations which serve as guides to total production that can be expected on different sites. These field plots sample many different thinning regimes and are likely to have been located in the more successful parts of the examined plantations. Degree and frequency of thinning in the production tables are prescribed by the authors, sometimes on the basis of experience with thinning trials of other conifers. As a result, there is more variation between tables in number of stems and average diameters specified for any age and site than in total volume production. These tables indicate higher potential gains in production and tree size from intensive thinning regimes than some previous local calculations and suggest that heavy thinning schedules have early culmination of volume production, and relatively short rotations.

Several production tables have been mentioned in North American literature (Barnes 1955, 1956; Barrett 1962; Briegleb 1952; Heiberg and Haddock 1955; Hoyer 1967; Staebler 1960; Warrack 1959).[1/] These tables were all from northern Europe, and some questions have been raised about effect of climatic differences on potential production. Although equally low average temperatures can be found at higher elevations in the Pacific Northwest, lack of summer dry

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1/ Names and dates in parentheses refer to Literature Cited, p. 16.

spells and resulting longer moist seasons in northern Europe could stimulate diameter growth more than height growth. This different balance of diameter and height growth would increase volume growth more than it would increase site index. It is not known how lower annual precipitation, shorter growing seasons, longer summer hours of daylight, and differences in soils affect the relation between height and diameter growth.

Therefore, production tables now available for mountainous areas of northern Italy and southern France are of particular interest. There, the latitudes and climates (mean annual temperature 48° to 50° F., rainfall 30 to 80 inches, and two dry summer months) correspond quite closely to those of Washington and Oregon.

Estimates of potential yields on a high site are available from New Zealand (Duff 1956; Spurr 1963). As will be seen later, it is difficult to distinguish possible effects on yield of differences in climate and soil from differences in thinning schedules and other causes. Data from all recent sources are presented and discussed.

BASES FOR COMPARISON

To make information in these production tables useful, it is necessary to identify them with areas of comparable productivity in the Pacific Northwest. The measure of productivity most often used in the Northwest is site index based on height of dominant and codominant trees at 100 years, as shown in U.S. Department of Agriculture Technical Bulletin 201 (McArdle et al. 1961). The European tables rate productivity on the basis of volume produced, but usually give either a stand mean height or an average height of some taller part of the stand, the latter corresponding closely, but not exactly, to height of dominants in natural stands. Johnston and Bradley (1963) point out that although the new British management tables classify stands on the basis of volume production, height-age relations are still used to determine yield class. They further state that the volume production in particular stands so classified may deviate from tabulated volume production by as much as 50 percent. Therefore, they introduce a secondary classification for local yields. This consists of three classes representing differences in mean annual production of about 22.6 cubic feet inside bark per acre centered around the production class indicated by the height-age relation.

Apparently, all European Douglas-fir production tables are for the coastal variety. Winter damage to coastal Douglas-fir planted in Prussia led to trials of the interior variety, but these were heavily damaged by needle disease (*Rhabdocline* sp.) (Kanzow 1937). Today, the only form other than coastal considered worth planting in most of Europe is an intermediate form from

British Columbia (Göhre 1958). Plantings of this form are generally too young to have been used as indicators of volume production.

Most but not all European volume figures include bark but exclude a low stump and the tip smaller than 3 inches in diameter outside bark. As well as could be determined, all ages were from date of germination, except in British and New Zealand tables where ages were from date of planting.

Since some of the tables ended at 50 years and total cubic-foot production culminated near that age, it was decided to compare production at that age. This reduces the number of production tables available for heavily thinned stands from three to two since a table from The Netherlands included only 30 years (Van Laar 1954).

Details of adjustments made to identify sites and to place all volume estimates on a common base are in Appendix I.

RESULTS OF COMPARISONS

Total production of thinned foreign plantations at 50 years (expressed as cubic feet under bark including tip and stump) ranged from about 75 to 400 cubic feet per acre per year (fig. 1). However, most estimates fell between 125 and 300 cubic feet. The average site index of stands producing 125 cubic feet appears to be about 95--the dividing line between sites IV and V.[2/] Production of 300 cubic feet per year for 50 years is indicated on an average site index of 155--between sites II and III. Site index 125 averages about 200 cubic feet total production. These average estimates of total production are higher than net yields tabulated by McArdle et al. (1961) or gross yields estimated by Staebler (1955b) and Curtis (1967) for natural stands in the Northwest (table 1). Differences between Staebler's gross yields, based on McArdle's temporary plots, and Curtis' gross yields, based on plot growth, are due in part to use of different data and in part to differences in analysis procedures. The closer approach of Curtis' estimates to the foreign production estimates indicates the possible error in estimating managed yields from normal yield tables for dense unmanaged stands derived from temporary plots.

2/ All site estimates in this paper are based on USDA Tech. Bull. 201, The Yield of Douglas-fir in the Pacific Northwest (McArdle et al. 1961).

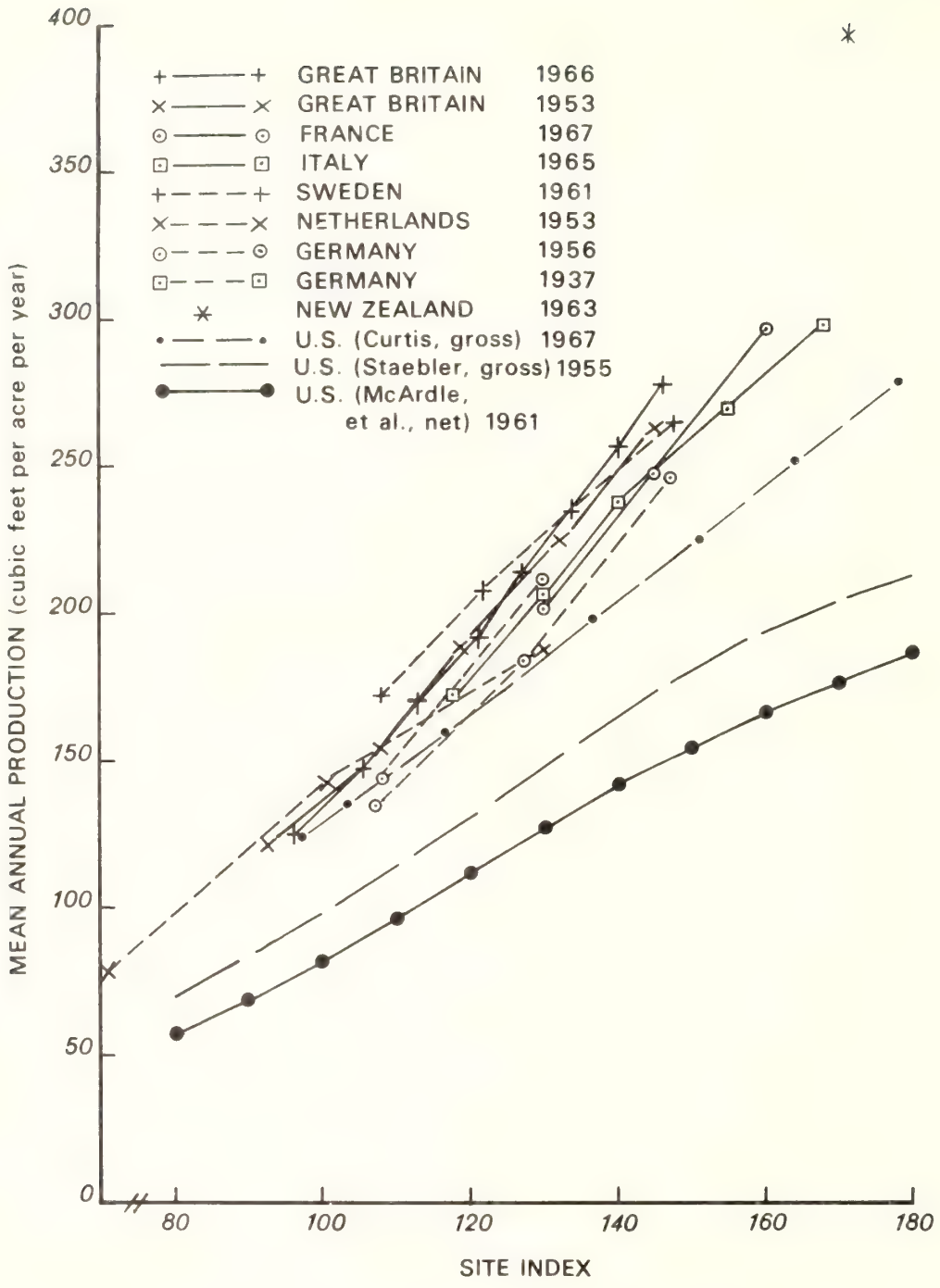

Figure 1.—Douglas-fir total production at about 50 years.

Table 1.--*Comparison of estimated yield of 50-year-old Douglas-fir stands*

Source of estimates	Site index		
	95	125	155
	------Cubic feet per acre per year------		
Foreign countries (total production of thinned plantations)	125	200	300
United States:			
McArdle et al. (1961) (net yield)	75	120	160
Staebler (1955b) (gross yield)	90	140	190
Curtis (1966) (gross yield)	120	175	235

These production figures are for fully stocked acres--for gross acreages, a reduction of 15 percent for roads, failed spots, and other openings, suggested by Bradley et al. (1966), seems reasonable for easy terrain. In rugged mountains, roads, rock outcrops, and other openings may take an even greater toll of productive area. These 50-year production rates are close to the maximum possible, since in these tables mean annual total production culminates at about 50 years on site 140 and 60 years on site 100 (fig. 2). (These "total" figures include both volumes to tip and to 3-inch top outside bark, since latter were adjusted by flat percentage which increases amount of volume production but has no effect on age of culmination of volume production.)

Only the British tables give information on volume production to other top limits. In these tables, culmination of mean annual "saw-log" production (volume to 7-inch top o.b.) is later than that of total production by 12 to 15 years. Culmination is based on seedling age to make it comparable with other data. Plantation age is 3 years lower. Volume production measured in cubic feet to a 7-inch top is about 80 percent of total production--in other words, about 20 percent of production is in trees or tops under 7 inches in diameter outside bark. Culmination of mean annual production at 65 to 80 years for volume to 7-inch top is earlier than indicated by McArdle (1961) for trees over 7 inches d.b.h. to a 5-inch top or than calculated by Staebler (1955a, 1955b) by addition of apparent mortality to normal net yield. Normal yield tables for natural stands are not well suited for calculation of rotations, even of natural stands, since they do not trace the growth of any stand.

It is likely that heavily thinned stands have shorter rotations than lightly thinned stands since repeated thinnings remove increasingly larger trees from the stand. The larger the holes the longer it takes surrounding trees to grow roots into the openings and otherwise adjust to their new environment. With heavy thinnings, a large percent of volume is removed early, and this reduction in stand efficiency may be felt at a younger age than with light thinnings.

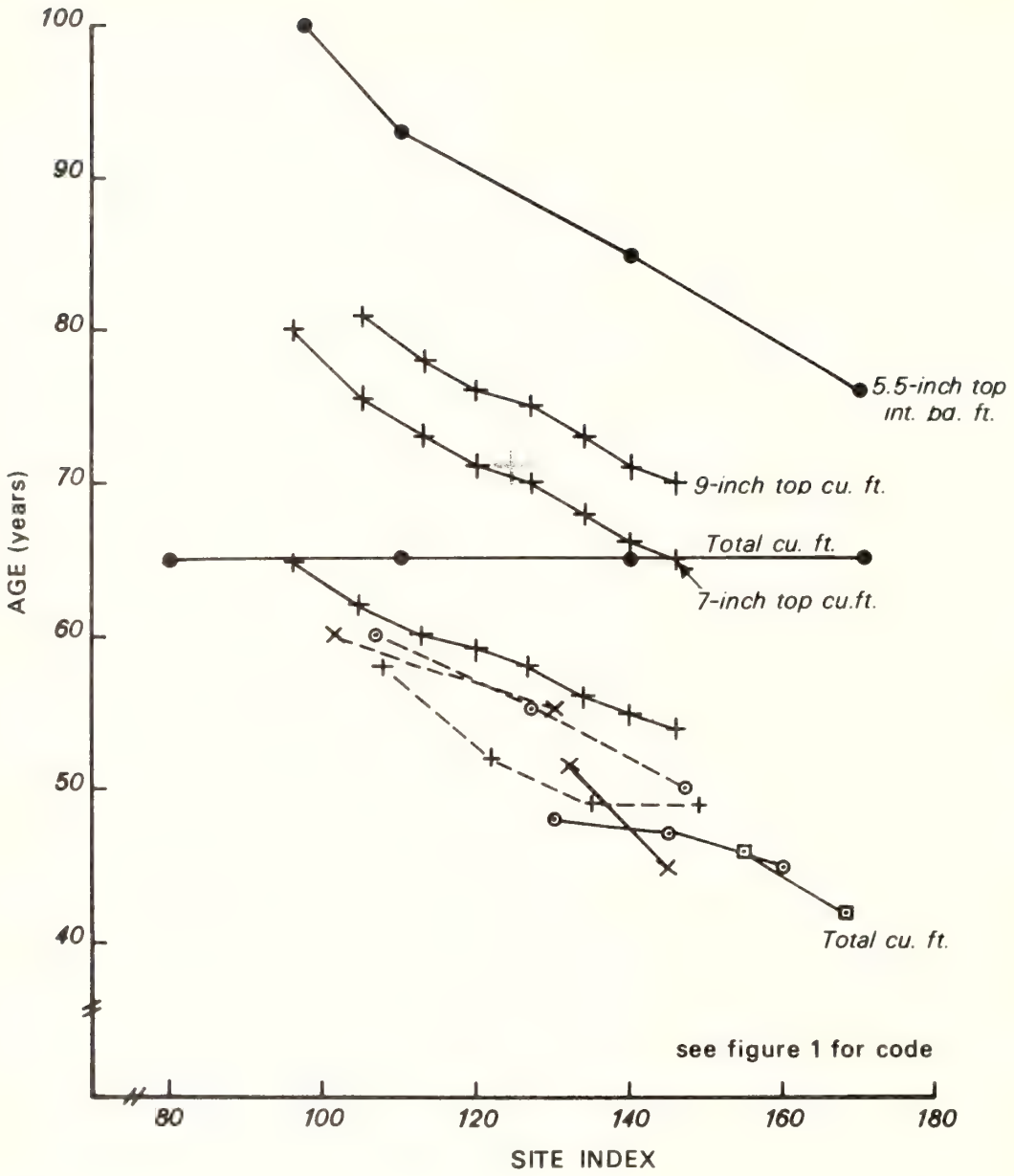

Figure 2.—Age at culmination of mean production. Numbers indicate top diameter outside bark.

Since the British tables suggest high-intensity thinnings, they offer no direct evidence about the effect of low-intensity thinning schedules on rotation length. However, as Johnston and Bradley (1963) point out, the highest intensity schedule that does not reduce total production is much closer to the schedule dictated by economic analysis than any lower intensity regime. At time of planting, values of early and heavy thinnings discounted at compound interest may exceed the value of the final harvest, despite the lower value of smaller trees.

A measure of thinning intensity is useful in consideration of the yields indicated by foreign tables. Thinning intensity is determined both by number and size of trees removed in each thinning and by frequency of thinning. Johnston et al. (1967) define thinning intensity as average annual volume removed between the time of first thinning and end of last thinning. They call the volume removed in a particular thinning the thinning weight and the interval between thinnings the thinning cycle. Since thinning intensity is cumulative, any measure of intensity other than volume removed must include the effects of early thinnings on stand growth. Such a measure is provided by Reineke's (1933) stand density index, which rates density on the basis of number per acre and quadratic mean diameter. Table 25 of Bulletin 201 provides an easy basis for relative density ratings that are equivalent to Reineke's ratings.

For a comparison of thinning intensities, relative stand densities in the production tables were based on average diameters and numbers of stems before and after thinning. The numbers of stems were expressed as a ratio to the numbers for corresponding diameters in table 25 of Bulletin 201. The average ratio midway between thinnings was plotted to indicate the changes over time in relative density for each thinning schedule (fig. 3). This graph suggests quite different thinning regimes. The ones starting before 20 years begin with moderate relative densities--those starting after 20 years begin with high relative densities. The earlier British tables (Hummel and Christie [illegible]) and the Netherlands tables (Grandjean and Van Soest 1953) suggest moderate relative stand densities and hence moderate thinning intensities throughout. The recent British tables (Bradley et al. 1966) and the Swedish tables (Karlberg 1961 pp. 60-64)[3/] start with moderate densities and then reduce stands to low densities--indications of high-intensity thinnings. Curves for French (Decourt 1967) and German (Schober 1957) schedules suggest initial light thinnings becoming heavier at older ages. The Italian thinning tables (Cantiani 1965) start with moderate-to-high stand densities and become even denser. This suggests progressively lower thinning intensity.

3/ Many of the data used by Karlberg were from the [illegible] that have been cited previously in American literature.

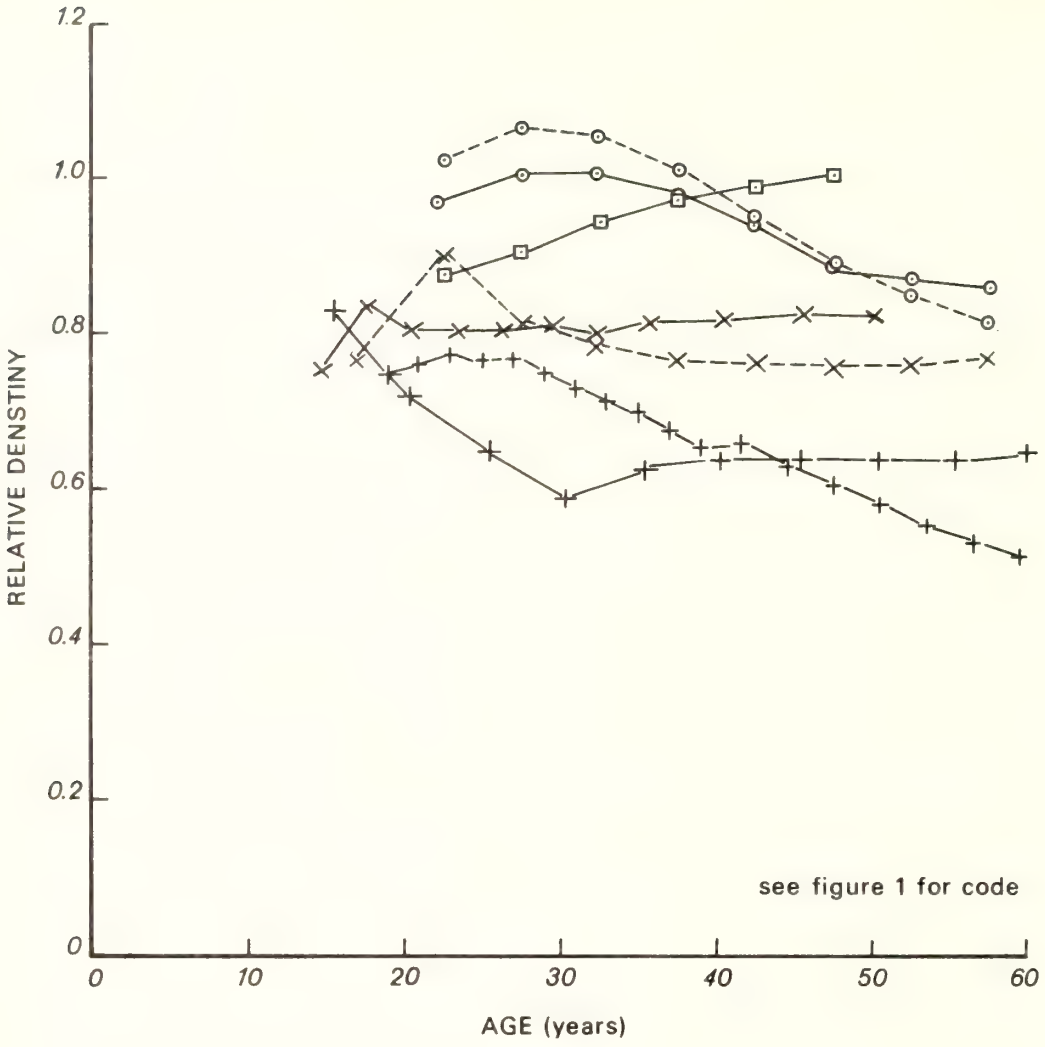

Figure 3.—Douglas-fir average relative density (site index range, 130-147).

When stand basal areas are substituted for stand density indexes in these comparisons, practically all stands are above normal at 25 years (fig. 4). This suggests Douglas-fir plantations generally can accrue basal area and volume faster at early ages than indicated by Bulletin 201. This is also true of some natural stands in the Pacific Northwest (Briegleb 1942). Some of the apparent differences in basal area can be attributed to differences in site index which had practically no effect on relative density comparisons.

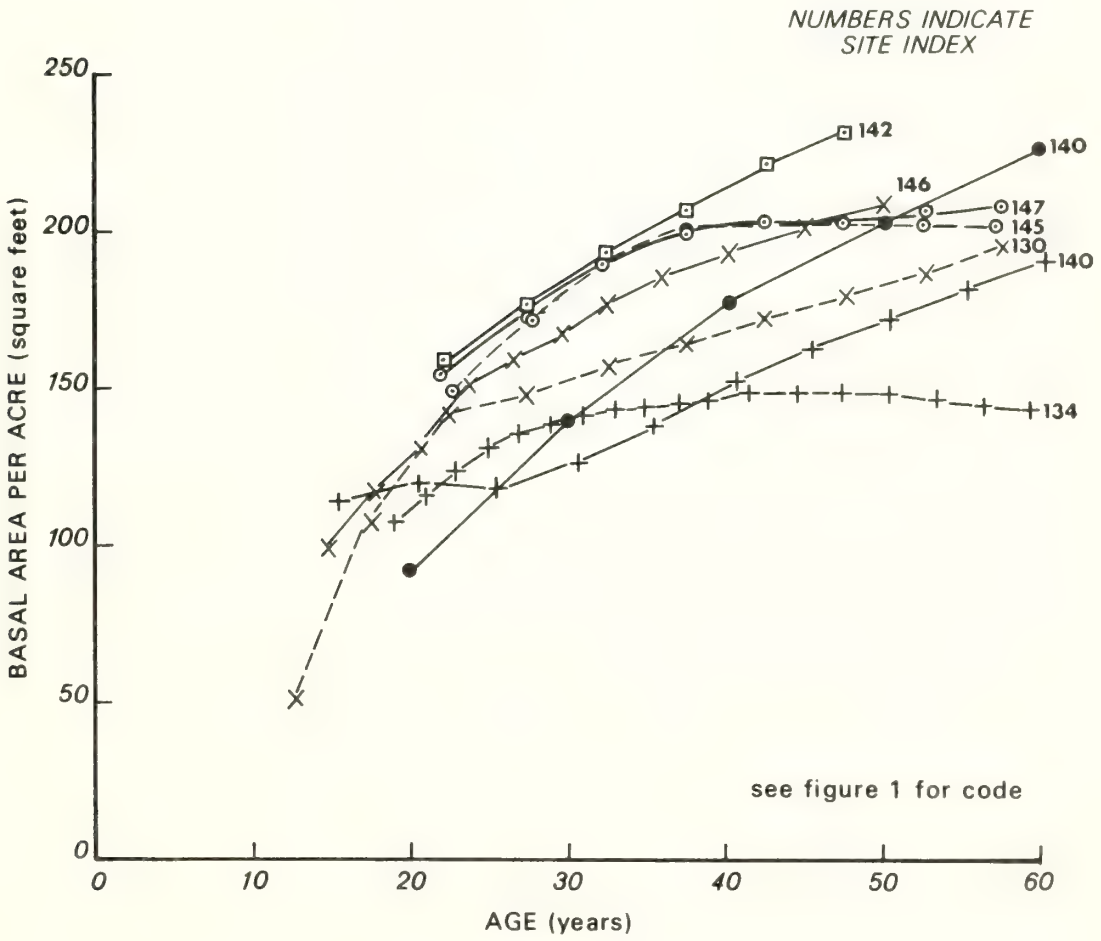

Figure 4.—Average basal area midway between thinnings (site index range, 130-147).

Basal area of residual stand at 50 years increases as site index increases (fig. 5). This increase is about 1 square foot per foot of site index. Relative amounts of basal area reflect the current weight of thinning at 50 years and because of the differences among thinning regimes cannot be related closely to total production. They are, however, closely related to volume of existing stand.

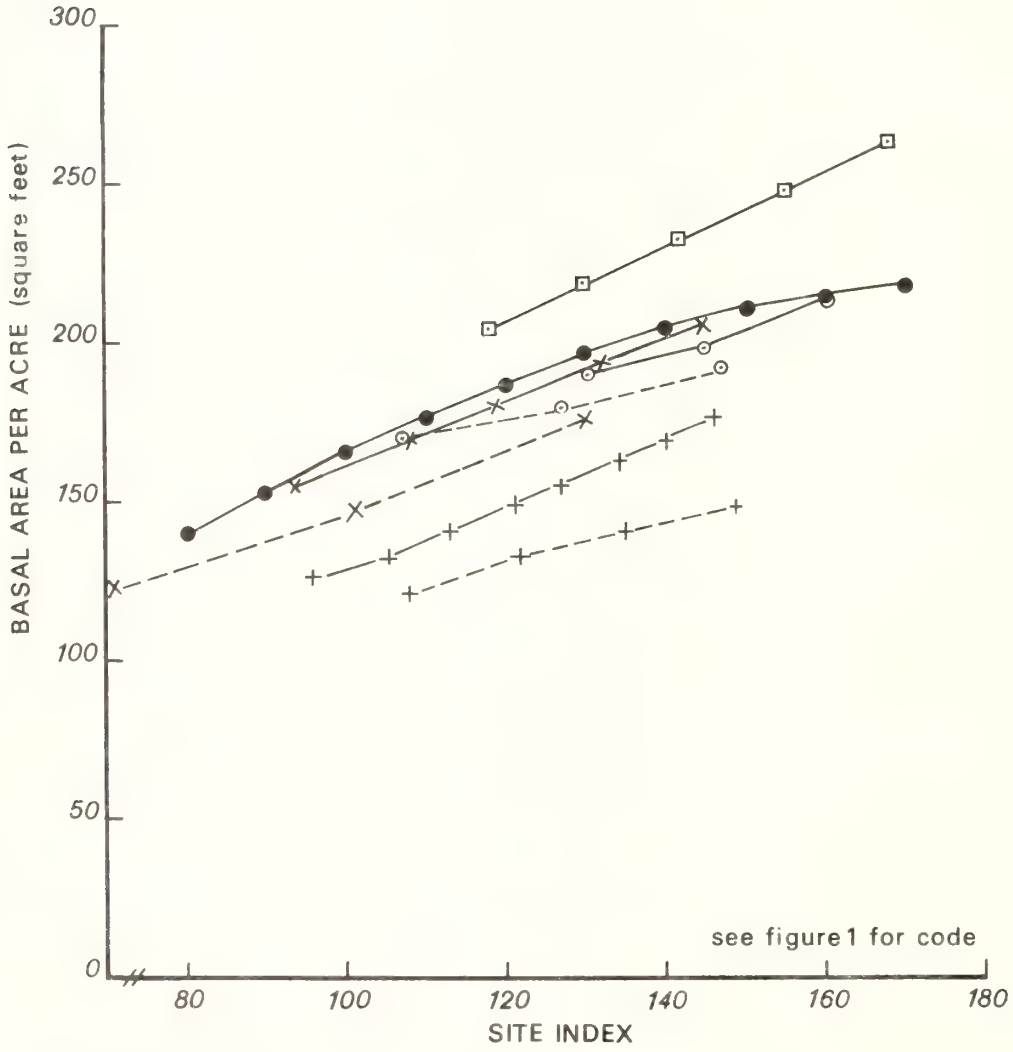

Figure 5. Basal area at age 50 – stand after thinning.

Another means of judging thinning intensity is by comparison of numbers of stems per acre in the middle of the thinning cycles (fig. 6). These figures alone could have little meaning since they do not specify size of tree. However, if it is assumed that on equal sites diameter growth is inverse to number of

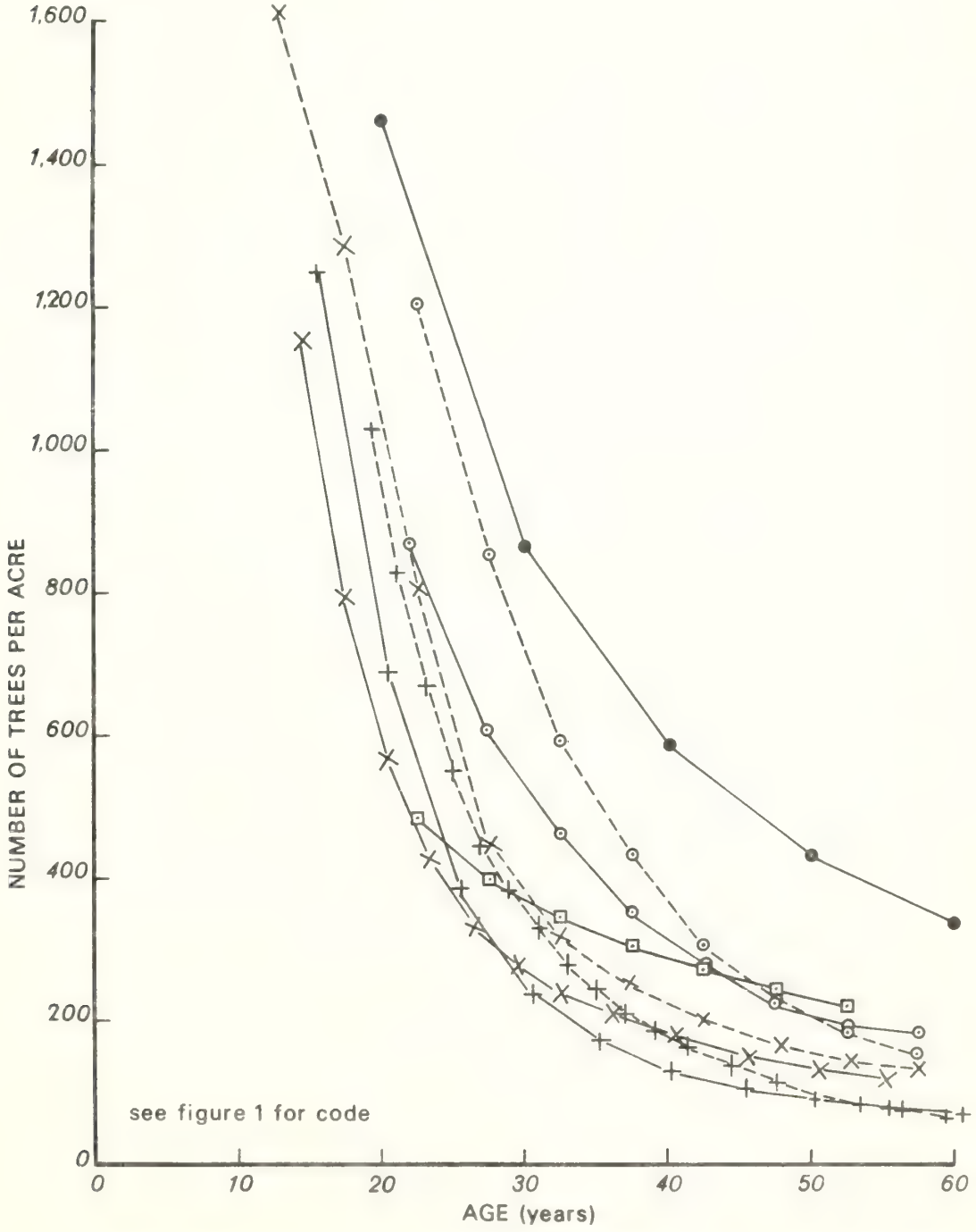

Figure 6. Number of trees per acre midway between thinnings (site index range, 130-147).

stems, the sequences with fewest stems can be considered high-intensity thinning schedules. Examination of mean diameters after thinning (fig. 7) bears this out. Stands carried at low numbers of stems have larger diameters than those carried at relatively high numbers. These diameters indicate average size of tree available for harvest at each age. Many small trees must be removed by thinning before final harvest of the larger trees.

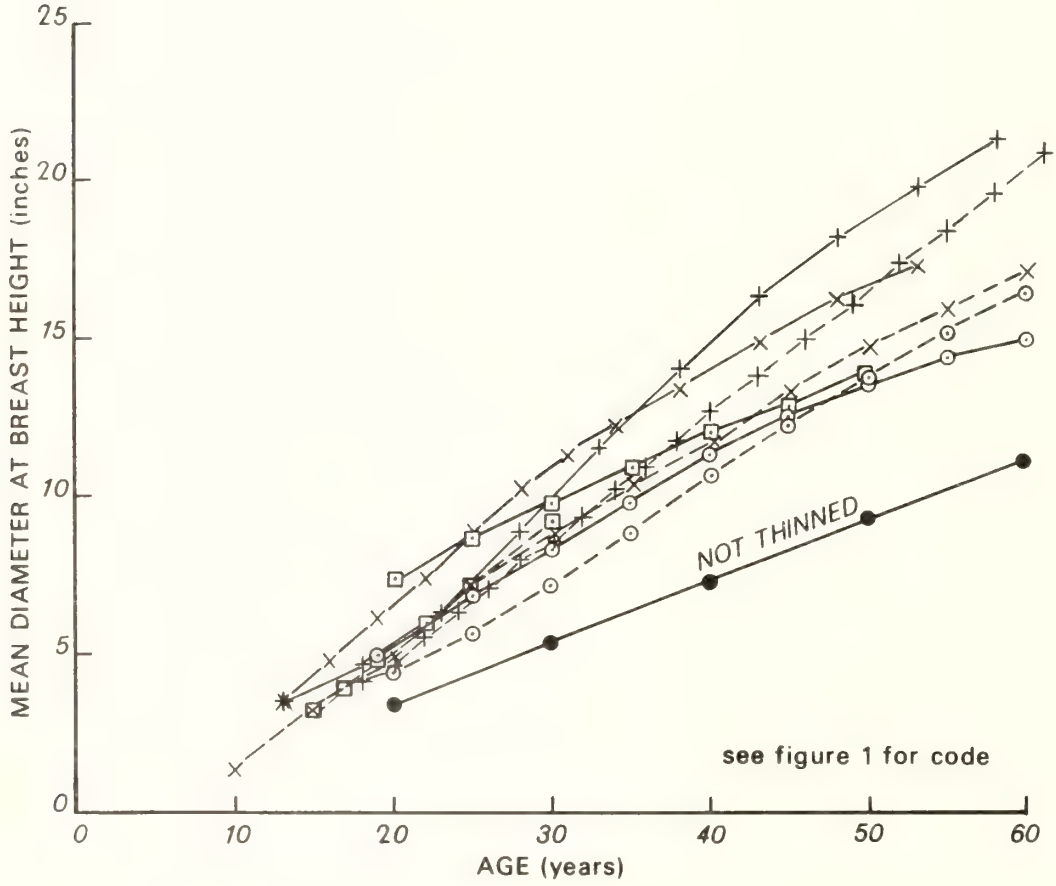

Figure 7.—Mean d.b.h. of residual stand immediately after thinning (site index range, 130-147).

Variations in thinning intensity appear to have less effect on total volume production than on average tree diameter (table 2).

Table 2.--*Stand statistics for age 50±, site 145±*

Country	Date published	Site index	Years from seed	Main crop				Production	
				Trees per acre	Mean d.b.h.	Basal area per acre	Volume per acre	Total	Mean annual
					In.	Sq.ft.	Cu.ft.	-----Cu.ft.-----	
Great Britain	1966	146	53	72	21.3	168	7,037	14,731	278
Great Britain	1953	145	53	125	17.2	205	8,238	13,915	263
France	1967	145	50	198	15.0	198	7,639	12,412	248
Italy	1965	142	50	225	13.8	225	8,875	11,912	238
Sweden	1961	149	49	86	17.8	149	5,719	13,043	266
Germany	1956	147	50	184	13.8	191	7,599	12,359	247

DISCUSSION

It was suggested that production tables from France and Italy might provide better estimates than those from more northern countries. Examination of the tables has suggested that thinning regimes prescribed for these two countries were much lighter than for most other countries, resulting in relatively low diameters at 50 years and relatively high basal areas and volumes in the residual stands. However, it is difficult to judge whether their somewhat low position in total volume production (fig. 1) is a result of climatic difference, thinning regime, or site classification. All indicated total production figures are encompassed in a band about 50 cubic feet wide (fig. 1). This is well within the limits of local yield variation reported by Johnston and Bradley (1963). If projected, this band would include the high yields reported in New Zealand.

Differences in average site index among production tables can be ascribed to both climate and soil. This average is 171 for New Zealand, 145 for France, 142 for Italy, and ranges from 128 to 101 for the northern countries. Differences between countries in climate and soil should cause similar differences in site index and volume production unless the climatic and edaphic differences affect the balance between diameter and height growth. Since figure 1 includes a wide

range of climates and soils, it is quite possible that Pacific Northwest yields would fall in the same 50-cubic-foot-wide band.

Highest volume production (in Sweden and Great Britain) is reported for thinning schedules with thinning starting before 20 years on site III and with high or moderate intensity thinnings. Generally, first thinnings are later on poorer sites. Thus, it seems reasonable to assume higher yields if thinnings start when top heights are 30 to 40 feet than if thinnings are postponed until top heights are 50 to 60 feet. These tables do not indicate the effect on yield of further postponement of thinnings.

All foreign production tables indicate thinnings at 2- to 5-year intervals. Johnston and Bradley (1963) suggest that there is little measurable difference in total yields if cycle is changed from 3 to 6 years on good sites or from 4 to 8 years on poor sites. It can be argued that repeated short delays in full site utilization in short thinning cycles have less effect on total volume production than fewer and longer delays with longer thinning cycles. This is mainly because the stand fluctuates less in relative density and area occupancy. Whether there is a measurable difference in production for 10-year thinning cycles compared with those in foreign tables is a moot question.

These production tables offer no information on increases in potential yields from intensive management practices other than thinning and weeding. In areas where brush and weeds can impede growth, weeding appears to be a standard practice in most foreign plantations. On soils where fertilizer improves tree growth, it is reasonable to assume that fertilizer application temporarily increases site productivity. Pruning has more effect on quality than on growth as long as it is limited to the lower live crown. Superior genetic stock in competition with inferior stock has dramatically better growth, and probably will have greater production when grown in solid blocks.

Forest managers in the Northwest cannot defer improved management of young Douglas-fir stands until pilot tests of planting and thinning can be completed. Other checks on these foreign thinning guides are possible. One key indicator of their applicability in the Pacific Northwest is current total annual increment. In the foreign tables on site 140, it culminates at 28 to 34 years, and mean total annual increment culminates at 49 to 52 years. In other species fully stocked when young, age at culmination of current annual increment (c. a. i.) is also about 60 percent of age at culmination of mean annual increment (m. a. i.). It can be shown that, if delays in regeneration are included in rotation calculations, a 5-year regeneration delay defers culmination of c. a. i. by 5 years but of m. a. i. by nearly 10 years. Therefore, accurate measurement of c. a. i. in younger stands will suggest approximate rotation lengths. Projection of c. a. i. and m. a. i. curves will indicate yields for these rotations. Rotations with maximum production to top limits of 6 inches to 8 inches probably will be 10 to 20 years longer, depending partly on site quality and partly on thinning intensity.

Investigations of the effect of precommercial thinnings in Douglas-fir stands are underway (Williamson and Staebler 1965) and should soon indicate if such

stands will reach the production levels attained in foreign-managed plantations. Other checks on these levels can be made in stands 20 to 50 years old that were planted at wide spacings or received early thinnings. These can be measured to get early verification of the indications of foreign management tables.

If assumptions about equivalence of sites and height adjustments were changed, the indications of potential yield and culmination of yield for specified sites would be changed. However, it would require large changes in assumptions or adjustments to affect results drastically. Therefore, the average indications presented here are available as guides to potential yields under management practices equal in intensity to those applied in foreign plantations until experience with managed stands in the Pacific Northwest can improve them.

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APPENDIX I

Adjustments Made

To equate production classes in foreign tables with Northwest site indexes, several assumptions about height at 50 years were made. It was assumed that top height (height of the largest 100 trees per hectare or 40 per acre) in plantations corresponds to height of dominants in natural stands and can be adjusted by Staebler's (1948) equation to get equivalent height of dominants and codominants in natural stands. No difference in height was allowed for various methods used to estimate this top height or for using in its place height of largest 10 percent of stand. Two feet were added to height of largest 100 trees per acre to get top height. Six feet were added to mean height[4/] to get top height.[5/]

Uniform adjustments were made for all sites because of evidence presented by Pardé (1956), Warrack (1959), Decourt (1967), and W. Flöhr in Gohre (1958). Pardé (1956) found that dominant height was 3.6 feet greater than mean height. Warrack (1959) added 5 feet to mean height to get height of largest 100 trees per acre. Decourt (1967) added 9 to 11 feet to mean height to get top height. A table published by Göhre (1958) suggests adding 6.5 feet to mean height to estimate top height. Hummel and Christie (1953) added about 3.5 feet to Lorey's mean height to get height of largest 100 per acre. A graph published by Tveite (1967) suggests mean height averages about a foot taller than Lorey's height in plantations.

Outside-bark volumes were adjusted by deducting 13 percent for bark. Hummel et al. (1951) suggest 12.5 percent, Warrack (1959) used 14 percent, and Decourt (1967) 12.7 percent. Kanzow (1937) used 12 percent for his sites I and II and 13 percent for sites III and IV. Bernetti (1964) shows a range of 15.0 to 11.7 percent decreasing with size with most values near 12 percent. Johnson's (1966) equations suggest a deduction of between 14 and 15 percent, but his study included larger trees than others.

Five percent was added to volumes that excluded stump and tip to put all volumes on the same basis as Bulletin 201. It was estimated that total volume in tips would range from 1.3 to 2.7 percent of total volume at 50 years, depending on number of stems in thinnings and remaining stand. Low stumps were estimated to include 3 percent of total stem volume.

[4/] Mean height in this paper is height of tree of mean basal area of entire stand.

[5/] This equally well could have been 7 feet which would increase all indicated site indexes by 1.4 feet. One reviewer suggested an adjustment varying with site which would reduce indicated site 80 to 78, increase 140 to 142 and 170 to 174.

British yield tables were based on planting seedlings 2 to 4 years old, so 3 years were added to plantation age in their production tables to make tree growth comparable to other tables (except in appendix II). It was assumed that 2-year-old stock is planted in New Zealand.

APPENDIX II

DOUGLAS-FIR PLANTATION YIELDS WITH HIGH INTENSITY THINNINGS

Since many American forest managers are not accustomed to thinking in terms of cubic feet, one of the British yield tables (Bradley et al. 1966) was converted to American units including estimates of board-foot yields (table 3). This table should not be used without appropriate reductions from full acre yields previously discussed. It should also be noted that its board-foot estimates are based on short log scaling rules. Further, this table is for site 140. On site 110, annual production culminates 8 years later with 50 percent more trees in the stand averaging about 18 inches d.b.h.

All converting factors are listed below, with the exception of conversions from cubic feet (7-inch o.b. top) to board feet (6-inch i.b. top) Scribner formula rule for 16-foot logs. The latter conversions are included in the body of the yield table since they vary with average tree size. They were determined by use of taper tables for Douglas-fir on site III (unpublished report, Pacific Northwest Forest and Range Experiment Station files, November 15, 1945) and tree dimensions determined from listed top heights and mean diameters at various ages. The average trees were scaled in both cubic feet and board feet in logs 16.3 feet long measured to nearest 0.1-inch d.i.b., except for the top fractional log which was scaled to the length and diameter shown in the taper table.

An approximate conversion to long-log Scribner scaling was calculated by applying long-log rules to the entire stem to 6-, 7-, and 8-inch tops. (A stem 103 feet to a 6-inch top was scaled as one 6-inch 32-foot, one 13-inch 34-foot, and one 17-inch 34-foot log.) The individual tree conversion ratios were extremely erratic, ranging from nearly equal to Scribner formula conversion ratios to 70 percent of them. A deduction of 20 percent appears appropriate for this table as an average conversion from 16.3 feet formula Scribner to long-log Decimal C Scribner.

Converting factors:

Quarter girth (in.) x 1.273 = diameter (in.)
Basal area quarter girth (sq. ft.) x 1.273 = basal area (sq. ft.)
Hoppus feet x 1.273 = cubic feet
(Cubic feet o.b. to 3 inches o.b.) x 0.89 = (cubic feet total i.b.)
(Cubic feet o.b. to 7 inches o.b.) x 0.84 = (cubic feet i.b. to 7 inches o.b. above stump)
1.14 x (Scribner formula bd. ft.) = International 1/4 inch bd. ft.
0.80 x (Scribner formula bd. ft.) = long-log Scribner Decimal C bd. ft.

Table 3 -- *Douglas-fir yield class 240 Hoppus feet (3 inches o.b.) (equal to 272 cu. ft. total r.b.→site index 140 feet)*

Based on British Forest Management Tables 1966, converted to American units, full-acre yields

Years after planting	Main crop--after thinning								Thinnings					
	Trees per acre	Top height (ft.)	Mean d.b.h. (in.)	Basal area per acre (sq. ft.)	Cubic-foot volume: Total	Cubic-foot volume: To 7-inch top, o.b.	Converting factor	Bd. ft., Scribner, to 6-inch top, i.b.	Trees per acre	Mean d.b.h. (in.)	Cubic-foot volume: Total	Cubic-foot volume: To 7-inch top, o.b.	Converting factor	Bd. ft., Scribner, to 6-inch top, i.b.
10	1,260	23.5	3.5	85	436	0	--	0	--	--	--	--	--	--
15	690	38.0	4.8	81	1,077	0	--	0	570	4.5	544	0	--	--
20	384	52.0	6.4	89	1,688	267	3.5	934	306	5.4	952	54	3.5	189
25	235	65.0	8.9	102	2,567	1,444	4.0	5,776	149	7.3	952	257	3.5	898
30	164	77.0	11.5	117	3,513	2,813	4.4	12,377	71	9.5	952	631	3.8	2,399
35	126	87.0	14.0	132	4,436	3,893	4.8	18,688	38	12.1	952	792	4.5	3,564
40	103	95.0	16.2	146	5,235	4,716	5.0	23,581	23	14.6	952	856	4.8	4,109
45	88	102.0	18.1	158	5,881	5,412	5.1	27,600	15	16.9	952	856	5.0	4,280
50	78	108.0	19.7	168	6,561	6,074	5.2	31,585	10	18.8	782	716	5.2	3,723
55	71	113.0	21.3	178	7,230	6,706	5.3	35,542	7	20.4	669	615	5.3	3,260
60	65	117.5	22.9	187	7,853	7,294	5.4	39,388	6	22.0	601	556	5.4	3,002
65	61	121.5	24.2	195	8,425	7,829	5.5	43,059	4	23.2	550	513	5.4	2,770
70	58	124.5	25.5	202	8,924	8,310	5.5	45,705	3	24.5	516	481	5.5	2,646
75	55	127.0	26.4	209	9,349	8,716	5.6	48,810	3	25.8	493	460	5.5	2,530
80	53	129.5	27.4	214	9,706	9,059	5.6	50,730	2	26.7	465	433	5.6	2,425

Years after planting	Total production				Mean annual production			Ratio: Main crop / Total production			Total production ratio: Cu. ft. 7-inch / Cu. ft. total
	Basal area per acre (sq. ft.)	Cubic-foot volume: Total	Cubic-foot volume: To 7-inch top, o.b.	Bd. ft., Scribner, to 6-inch top, i.b.	Cubic-foot volume: Total	Cubic-foot volume: To 7-inch top, o.b.	Bd. ft., Scribner, to 6-inch top, i.b.	Cubic-foot volume: Total	Cubic-foot volume: To 7-inch top, o.b.	Bd. ft., Scribner, to 6-inch top, i.b.	
10	85	436	0	0	44	0	0	1.00	--	--	0
15	143	1,621	0	0	108	0	0	.66	--	--	0
20	201	3,184	321	1,123	159	16	56	.53	0.83	0.83	0.10
25	257	5,015	1,755	6,863	201	70	275	.51	.82	.84	.35
30	309	6,913	3,755	15,863	230	125	529	.51	.75	.78	.54
35	355	8,788	5,627	25,738	251	161	735	.50	.69	.73	.64
40	395	10,539	7,306	34,740	263	183	868	.50	.65	.68	.70
45	429	12,137	8,858	43,039	270	197	956	.48	.61	.64	.73
50	460	13,599	10,236	51,020	272	205	1,020	.48	.59	.62	.75
55	486	14,935	11,483	57,964	272	209	1,054	.48	.58	.61	.77
60	510	16,159	12,627	64,812	269	210	1,080	.49	.58	.61	.78
65	531	17,281	13,675	71,253	266	210	1,096	.49	.57	.60	.79
70	549	18,295	14,637	76,545	261	209	1,094	.49	.57	.60	.80
75	565	19,213	15,503	82,180	256	207	1,096	.49	.56	.59	.81
80	574	20,035	16,279	86,525	250	203	1,082	.48	.56	.59	.81

Bruce, David.
1969. Potential production in thinned Douglas-fir plantations. USDA Forest Serv. Res. Pap. PNW-87, 22 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Nine foreign production tables for Douglas-fir (thinning guides) were converted to American units of measure. They suggest that potential yields of thinned stands in the Pacific Northwest are higher than has been estimated on the basis of natural unthinned stands, and that culmination of merchantable mean annual production with heavy thinning may occur at 65 to 80 years.

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THE ECONOMICS OF CONVERTING RED ALDER TO DOUGLAS-FIR

BY JAMES G. YOHO ▪ DANIEL E. CHAPPELLE ▪ DENNIS L. SCHWEITZER

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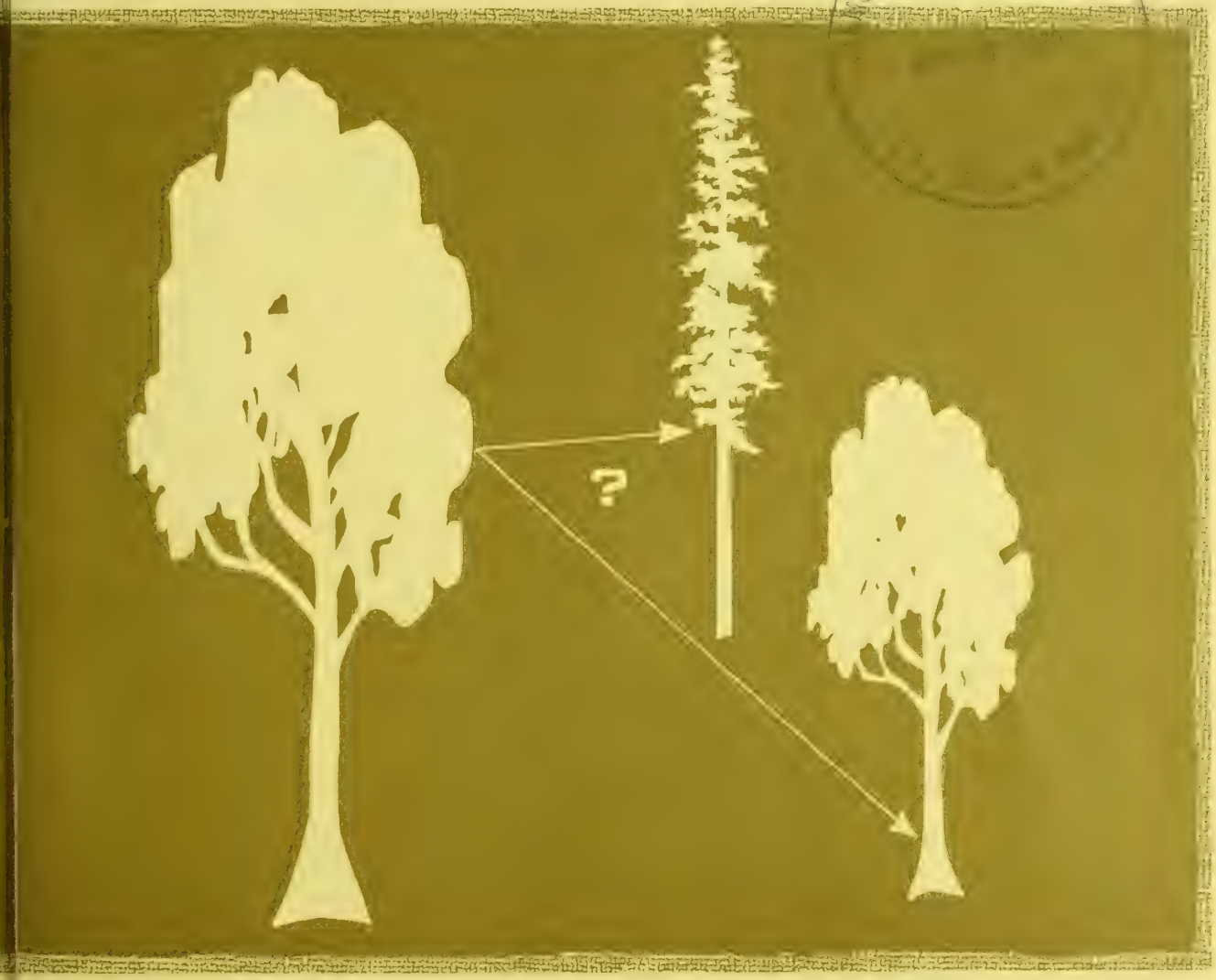

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PORTLAND, OREGON 1969

Table 1.--*Types of costs and returns assumed relevant to deciding whether a red alder stand should be retained or replaced by Douglas-fir*

Retain red alder		Years of occurrence	Convert red alder stand to Douglas-fir	
Incomes	Costs		Incomes	Costs
		BEFORE CONVERSION	Red alder liquidation (once at conversion)	Management (annually until conversion)
Red alder clearcut (repeated in each rotation)	Management (annually)	CONVERSION		Site preparation (once for liquidated stands less than 30 years of age)
		AFTER CONVERSION	Douglas-fir thinnings and final harvest (repeated in each rotation)	Establishment (repeated in each rotation) Brush control (repeated in each rotation) Management (annually)

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INTRODUCTION

For many years, the old-growth Douglas-fir forests of the Pacific Northwest have supplied a major portion of the Nation's timber. Efforts to renew these forests for a second crop of Douglas-fir have frequently been hampered by the presence of less desirable species, principally red alder, which have invaded cutover areas. Over time, an increasing supply of red alder has led to the development of new uses for the species and a subsequent increase in its value. Now, many forest managers must decide whether to manage for red alder or to replace it with Douglas-fir. This paper deals with the economics of this decision: Should an existing stand of red alder be retained or should it be converted to Douglas-fir? If it is to be converted, when? [1]

A premise of this study is that the forest manager sees red alder as a problem. Compared with Douglas-fir, red alder is a "Johnny-come-lately" that many foresters feel is unworthy of serious consideration. Others consider the species to be a real economic windfall. In any case, we are here interested in developing analytical approaches that will permit managers to make rational decisions regarding the retention or replacement of red alder stands.

Conversion of a young red alder stand to Douglas-fir requires a relatively large capital outlay that may be wholly or partially avoided by a few years' wait for the stand to reach merchantable size. The length of this waiting period depends on the productivity of the site. The financial returns depend on the direct costs of conversion, management costs, the anticipated harvesting regime, future prices, and the firm's opportunity cost of capital. Thus, the two simple alternatives of retaining red alder or converting to Douglas-fir lead to numerous investment management possibilities.

In this study, we concentrated on defining "favorable" and "unfavorable" situations for retaining red alder or for converting to Douglas-fir. We aimed at answering questions such as, "Given this red alder stand on this site, these yields, costs, and prices, would one be better off managing for red alder or converting (in how many years?) the stand and then managing for Douglas-fir?" This analysis is essentially a series of case studies where the number of cases considered is vast; however, that number is still minute when compared with all the possibilities if every conceivable set of assumptions were considered. For this reason, our findings should be applied to the specific problems of a particular ownership with caution.

---

[1] *The management and utilization of red alder are outlined by Worthington et al. (1962) and the production and marketing of the species by Yoho et al. (1969).*

No informal observations, let alone research data, outside of those developed in this study, have ever been systematically collected and summarized for most aspects of this conversion decision. Therefore, so that precision in calculating the absolute profitability of each alternative would not be critical, we developed guidelines that indicate whether or not red alder stands should be converted, given particular sets of assumptions. Ranges of stumpage prices, guiding rates of return, conversion costs, and annual management costs which bracketed nearly all cases found in practice were considered in the analysis.

This study might be criticized as premature because the input data are not firm enough to justify the derivation of management guides. The obvious answer is to pose a question--"How are these decisions being made now?" On reflection, the answer will have to be that such decisions are indeed being made now--made not only on the basis of flimsy or partial data but upon poorly conceived models as well. Decisionmakers in all fields of management must use the best information available to them, after tempering it with their individual insights. The objective of this paper was to provide well-defined guidelines based on explicit values of the relevant variables.

The tentative management guides presented here will be adequate for a given firm if (1) the firm's situation falls within the range of cases analyzed in this study, or (2) it is shown that the conversion decision is not sensitive to the out-of-range variables. If neither of these conditions holds, the reader can insert his own values into the analytical model. [2]

THE ANALYTICAL MODEL AND ASSUMPTIONS

The first and most basic assumption of the analysis is that the manager wants to maximize present net worth per acre, either by extensively managing (without thinning) red alder or intensively managing (with thinning) Douglas-fir on the same sites. It is further assumed that he is not hampered by limitations or shortages of money, equipment, or labor. Here, it has merely been suggested that costs, in terms of forgone income, accompany such limitations (see the subsection entitled "Scheduling Stand Conversion").

Essentially, the analytical approach was to calculate the present net worths of the perpetual management of red alder for a range of costs and returns and to compare them with the present net worths that could be anticipated from liquidating the existing red alder stands and the subsequent perpetual management of Douglas-fir on the same sites. The costs and incomes relevant to these calculations are listed in table 1, which is printed on the inside of the front cover. (Sample calculations illustrating the entries in this table and utilizing the equations given below are included in Appendix B.) The relative sizes of these costs and incomes, based on middle-of-the-range assumptions, are suggested by figure 1.

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[2] *Listings of two computer programs developed to perform the necessary calculations are available upon request from Director, Pacific Northwest Forest & Range Experiment Station, P.O. Box 3141, Portland, Oregon 97208.*

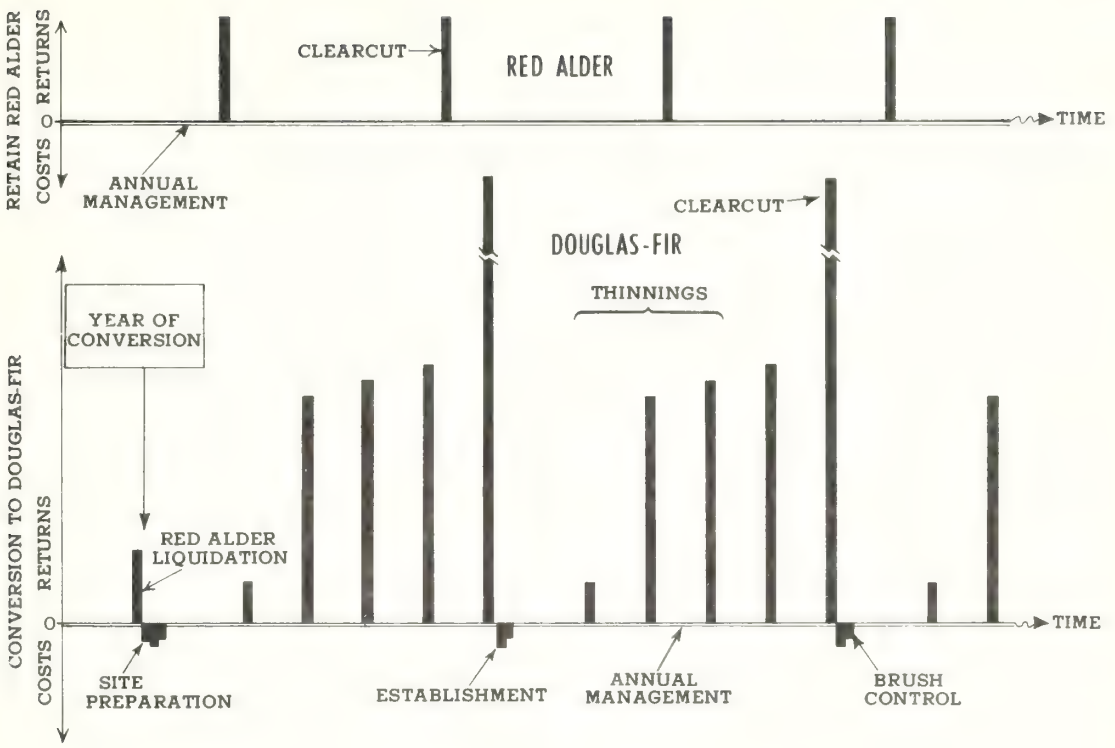

Figure 1.—Representative costs and returns to be expected from retaining red alder and from liquidating red alder and converting the site to Douglas-fir production.

Because the advantages of growing two different species on the same ground had to be compared, it was necessary to relate the productive capacity of the site for red alder to that for Douglas-fir. After the sparse available evidence was examined, the equivalences of site classes for the two species shown in table 2 were assumed.[3] In the same table, the assumptions concerning rotation lengths for each of the species on each site have been summarized.

THE PRESENT NET WORTH OF RETAINING RED ALDER

The gross returns to be expected from managing red alder (without thinning) for both pulpwood and sawtimber are shown in table 3. Stands now between 15 and 65 years of age on site indexes 70, 90, and 110 are included. High,

[3] *Red alder stands on sites wet enough to hamper Douglas-fir growth are excluded from the study. Also excluded for lack of sufficient data are the economic values derived from alder on certain sites; e.g., the increase of site quality through nitrogen fixing and the control of Poria weirii Murr., cause of a root rot of Douglas-fir.*

Table 2.--*Assumed correlations of red alder and Douglas-fir site indexes and corresponding rotation lengths*

Red alder		Equivalent site class[3]	Douglas-fir	
Rotation[1]	Site index[2]		Site index[4]	Rotation[1]
65 years	70 feet	70/IV	110 feet (IV)	100 years
55 years	90 feet	90/III	140 feet (III)	85 years
45 years	110 feet	110/II	170 feet (II)	70 years

[1] Assumed rotation lengths are representative of those used in practice.

[2] Red alder site indexes are on a 50-year basis.

[3] Equivalences of site indexes are based on a consensus of expert opinions. See the footnotes on pages 3 and 15.

[4] Relation of Douglas-fir site quality classes to site indexes (at 100 years) based on McArdle et al. (1949).

Table 3.--*Expected gross returns per acre from red alder management*[1]

Stand age (years)	Stumpage price levels[2] for-- Red alder/Douglas-fir site class 70/IV			Red alder/Douglas-fir site class 90/III			Red alder/Douglas-fir site class 110/II		
	$7.50/$21	$4.50/$12	$1.50/$4	$7.50/$21	$4.50/$12	$1.50/$4	$7.50/$21	$4.50/$12	$1.50/$4
	Dollars per acre								
15	39.15	23.49	7.83	75.00	45.00	15.00	110.02	66.01	22.02
25	125.02	75.01	25.00	191.70	115.00	38.34	258.30	154.98	51.66
35	193.35	116.01	38.67	291.67	175.00	58.33	372.21	218.37	72.79
45	245.83	147.51	49.17	366.40	211.63	70.54	520.24	299.23	99.74
55	272.40	157.68	52.56	455.70	261.90	87.30	--	--	--
65	301.98	173.94	57.98	--	--	--	--	--	--

[1] Based on Appendix A, table 13.

[2] Stumpage price levels are read, for example, as "$7.50 per cord for pulpwood and $21 per M bd. ft. for sawtimber."

medium, and low prices, intended to bracket most situations, were applied to generate the table values. (The underlying physical yield tables are given in Appendix A.)

The value of a perpetual series of red alder rotations, when discounted to the present, is given by:

$$\left[\begin{array}{c}\text{Present value of}\\ \text{perpetual series}\\ \text{of red alder yields}\end{array}\right] = \left[\begin{array}{c}\text{Value at}\\ \text{final}\\ \text{harvest}\end{array}\right] \times \left[\frac{(1+p)^{s}}{[(1+p)^{s}-1](1+p)^{s-j}}\right]$$

where

p = decimal form of guiding rate of return,[4]
s = red alder rotation length in years, and
j = present age of stand.

The only cost of red alder management that was considered was a constant annual cost which was assumed to include protection, administration, and property taxes. In the subsequent analysis, two levels of this cost were used, $1 and $0.50 per acre. The present value of these costs is given by:

$$\left[\begin{array}{c}\text{Present value of}\\ \text{annual red alder}\\ \text{management costs}\end{array}\right] = \left[\begin{array}{c}\text{Annual}\\ \text{costs}\end{array}\right] \times \left[\frac{1}{p}\right]$$

Finally, then, the value of a given alternative can be calculated as follows:

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of retaining}\\ \text{red alder}\end{array}\right] = \left[\begin{array}{c}\text{Present value of}\\ \text{perpetual series of}\\ \text{red alder yields}\end{array}\right] - \left[\begin{array}{c}\text{Present value of}\\ \text{annual red alder}\\ \text{management costs}\end{array}\right]$$

THE PRESENT NET WORTH OF REPLACING RED ALDER WITH DOUGLAS-FIR

As is apparent in table 1, calculating the value of converting red alder to Douglas-fir is somewhat complex. The costs and incomes fall into three categories:

1. The annual costs of managing and the one-time returns from liquidating the present red alder stand BEFORE CONVERSION,
2. Site preparation required at CONVERSION before Douglas-fir can be established, and
3. Those costs and returns resulting from managing Douglas-fir to perpetuity in the AFTER CONVERSION period.

---

[4] *For a discussion of the concept of the guiding rate of return, see Duerr (1960, pp. 143-150) or Pacific Northwest Forest & Range Experiment Station (1963, pp. 13-16).*

Income and Costs BEFORE CONVERSION

The present value of the existing red alder stand that is to be liquidated is given by:

$$\left[\begin{array}{c}\text{Present value of}\\ \text{existing red alder stand}\end{array}\right] = \left[\begin{array}{c}\text{Value at time}\\ \text{of liquidation}\end{array}\right] \times \left[\frac{1}{(1+p)^{c}}\right]$$

where

p = decimal form of guiding rate of return and
c = number of years until conversion (liquidation).

Again, we relied on table 3 for estimates of the value of the stand when it is liquidated. Since age of the youngest red alder stand considered is 15 years and the oldest 65 years, the number of years until conversion (c) can vary from 0 to 50 years, by 10-year increments.

Necessarily, we considered the annual costs of protecting, administering, and paying property taxes:

$$\left[\begin{array}{c}\text{Present value of annual red}\\ \text{alder management costs}\end{array}\right] = \left[\begin{array}{c}\text{Annual}\\ \text{costs}\end{array}\right] \times \left[\frac{(1+p)^{c}-1}{p(1+p)^{c}}\right]$$

This permitted writing the current value of the red alder stand now on the ground as:

$$\left[\begin{array}{c}\text{Present net worth of}\\ \text{existing red alder}\\ \text{stand BEFORE CONVERSION}\end{array}\right] = \left[\begin{array}{c}\text{Present value of}\\ \text{existing red}\\ \text{alder stand}\end{array}\right] - \left[\begin{array}{c}\text{Present value of}\\ \text{annual red alder}\\ \text{management costs}\end{array}\right]$$

Costs at CONVERSION

We assumed that replacing red alder by Douglas-fir would require special site preparation if the original red alder stand were less than 30 years old when liquidated; if older, no special cost was considered (logging in older stands was assumed to insure adequate site disturbance). It was assumed that either scarification or aerial spraying might be used, depending on such factors as the density of understory brush. Cost levels for such operations representative of many conditions are given in table 4.

Since site preparation was assumed to be required only once, c years from now at the time of conversion, its value is given simply as:

$$\left[\begin{array}{c}\text{Present net worth of}\\ \text{site preparation costs}\\ \text{at CONVERSION}\end{array}\right] = \left[\begin{array}{c}\text{Cost at}\\ \text{time of}\\ \text{conversion}\end{array}\right] \times \left[\frac{1}{(1+p)^{c}}\right]$$

Table 4.--*Representative levels of costs of conversion to Douglas-fir*

Cost level	Incurred once--at CONVERSION	Incurred in each Douglas-fir rotation--AFTER CONVERSION	
	Site preparation[1/]	Establishment	Brush control
	Dollars per acre		
High	70	80	40
Medium	40	50	25
Low	10	20	10

[1/] A zero cost has been assumed whenever the red alder stand to be liquidated is more than 30 years old.

Incomes and Costs AFTER CONVERSION

We assumed that Douglas-fir must be artificially established at the beginning of each rotation, either by planting or direct seeding. Alternative cost levels that were employed are shown in table 4. The present value of this periodic cost was calculated as follows:

$$\left[\begin{array}{c}\text{Present value of cost of periodically establishing Douglas-fir}\end{array}\right] = \left[\begin{array}{c}\text{Cost at time of conversion and at start of all future stands}\end{array}\right] \times \left[\frac{(1+p)^t}{[(1+p)^t - 1](1+p)^e}\right]$$

where t = Douglas-fir rotation length in years.

Maintenance of the newly established and all future Douglas-fir stands was assumed to require control of brush and alder seedlings by aerial spraying 5 years after establishment. The present value of this periodic cost was calculated as follows:

$$\left[\begin{array}{c}\text{Present value of cost of periodic brush control}\end{array}\right] = \left[\begin{array}{c}\text{Cost 5 years after establishment}\end{array}\right] \times \left[\frac{(1+p)^t}{[(1+p)^t - 1](1+p)^{e+5}}\right]$$

Again, representative cost levels are given in table 4.

The final assumed costs of managing Douglas-fir were the (constant) costs of protection, administration, and taxes. Combined, these were estimated at two levels of $0.60 and $1.60 per year. Their present values were calculated in the following fashion:

$$\left[\begin{array}{c}\text{Present value of annual Douglas-fir management costs}\end{array}\right] = \left[\begin{array}{c}\text{Annual costs}\end{array}\right] \times \left[\frac{1}{(1+i)^e}\right]$$

The values that we anticipate from thinning and clearcutting in Douglas-fir are shown in table 5 for a variety of stumpage price levels. This information is all that is required to calculate the present values of the returns from perpetual series of Douglas-fir rotations which will begin when the existing stand of red alder is liquidated.

$$\left[\begin{array}{c}\text{Present value of}\\ \text{perpetual series of}\\ \text{Douglas-fir yields}\end{array}\right] = \left[\frac{(1+p)^t}{[(1+p)^t - 1](1+p)^c}\right] \sum_{\text{first thinning}}^{\text{final harvest}} \left[\begin{array}{c}\text{Value of}\\ \text{thinning}\\ \text{or final}\\ \text{harvest}\end{array}\right] \times \left[\frac{1}{(1+p)^g}\right]$$

where

t = Douglas-fir rotation length in years and
g = number of years from establishment until thinning or final harvest occurs.

The incomes and costs related to Douglas-fir management can all be brought together by the following expression:

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of perpetual}\\ \text{Douglas-fir}\\ \text{management}\\ \text{AFTER CONVERSION}\end{array}\right] = \left[\begin{array}{c}\text{Present value of}\\ \text{perpetual series}\\ \text{of Douglas-fir yields}\end{array}\right] - \left[\begin{array}{c}\text{Present value of cost}\\ \text{of periodically}\\ \text{establishing Douglas-fir}\end{array}\right]$$

$$- \left[\begin{array}{c}\text{Present value of}\\ \text{cost of periodic}\\ \text{brush control}\end{array}\right] - \left[\begin{array}{c}\text{Present value of}\\ \text{annual Douglas-fir}\\ \text{management costs}\end{array}\right]$$

Finally, the following equation summarizes the discounted incomes and costs encountered when replacing red alder with Douglas-fir:

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of converting red}\\ \text{alder to Douglas-fir}\end{array}\right] = \left[\begin{array}{c}\text{Present net worth of}\\ \text{existing red alder}\\ \text{stand BEFORE CONVERSION}\end{array}\right] - \left[\begin{array}{c}\text{Present net worth of}\\ \text{site preparation costs}\\ \text{at CONVERSION}\end{array}\right]$$

$$+ \left[\begin{array}{c}\text{Present net worth of}\\ \text{perpetual Douglas-fir}\\ \text{management AFTER CONVERSION}\end{array}\right]$$

Again, with reference to table 1, it can be seen that all relevant costs and incomes have been incorporated into the analytical model. Moreover, the present net worths of both retaining red alder and of replacing it with Douglas-fir can be calculated and compared, given a number of explicit assumptions. For those who cannot accept these assumptions, a later section of this paper reports the results of a sensitivity analysis which identifies the variables most critical to the retain or replace decision. The costs of delaying conversion past the recommended time also have been explored briefly.

Table 5.--*Expected gross returns per acre from Douglas-fir management with thinnings*[1/]

Stand age (years)	Stumpage price levels[2/] for--								
	Red alder/Douglas-fir site class 70/IV			Red alder/Douglas-fir site class 90/III			Red alder/Douglas-fir site class 110/II		
	$55/$70	$45/$60	$18/$22.50	$55/$70	$45/$60	$18/$22.50	$55/$70	$45/$60	$18/$22.50
	Dollars per acre								
25	0	0	0	126.50	103.50	41.40	533.50	436.50	174.60
40	181.50	148.50	59.40	687.50	562.50	225.00	940.50	769.50	307.80
55	297.00	243.00	97.20	737.00	603.00	241.20	1,127.50	922.50	369.00
70	605.00	495.00	198.00	781.00	639.00	255.60	3,626.00	3,108.00	1,165.50
85	429.00	351.00	140.40	2,324.00	1,992.00	747.00	--	--	--
100	1,673.00	1,434.00	537.75	--	--	--	--	--	--

[1/] Based on Appendix A, table 14.

[2/] Stumpage prices are read, for example, as "$55 per M bd. ft. for thinnings and $70 per M bd. ft. for final harvests." In each column, the first price was used to generate the value of all thinnings, the second price to generate the final harvest value of the residual stand at the end of the rotation, which is the last value in each column.

RESULTS OF THE ANALYSIS

In the preceding section, the analytical model and assumptions of the study were outlined. In this section, the results of the analysis are reported and interpreted. Specifically, the data of tables 3 and 5 (expected gross returns), table 4 (conversion costs), and table 6 (stumpage prices and annual management costs) are the assumed values which led to the solutions presented in the composite table 7. A discussion of the impacts on the conversion decision of changes in these fundamental assumptions has been deferred to the next section.

All of the entries in the composite table are defined as the optimal number of years to wait before replacement of an existing red alder stand with one of Douglas-fir. A zero means the red alder stand should be replaced immediately. An "R" means that red alder should be managed in perpetuity. (Boldface entries indicate "borderline" cases which are discussed in the next section under "A General Sensitivity Analysis.") The upper left-hand portion of the table summarizes all decisions involving the assumption of high stumpage prices and low management costs. It tells us, for example, that given low conversion costs, a 6-percent rate of return, and a 15-year-old red alder stand on site 90 land, the manager should immediately clearcut the alder and replace it with Douglas-fir. In contrast, if the same red alder stand were appraised under medium stumpage prices (left center), the most desirable action would be to wait 10 years before liquidation and conversion to Douglas-fir. The other tables should be read and interpreted in a similar fashion. In this way, they can serve as guides to management if the model, data, and assumptions are appropriate. If they are not appropriate, a customized analysis will be required.

Table 6.--*Stumpage prices and annual management costs assumed in the basic analysis*

Item	Assumed price and management cost levels		
	High	Medium	Low
	----------*Dollars*----------		
STUMPAGE PRICES			
Red alder:			
Pulpwood (per cord)	7.50	4.50	1.50
Sawtimber (per M bd. ft.)	21.00	12.00	4.00
Douglas-fir:			
Thinnings (per M bd. ft.)	55.00	45.00	18.00
Clearcut (per M bd. ft.)	70.00	60.00	22.50
MANAGEMENT COSTS			
Red alder (per acre per year)	1.00	--	.50
Douglas-fir (per acre per year)	1.60	--	.60

It is important to keep in mind that the entries indicate which alternatives have the larger present net worths. Following these recommendations would not necessarily insure a profit. In fact, the blocked recommendations, which are found under low or medium prices, are for loss-minimizing courses of action. Under these adverse conditions of low stumpage values and high costs, choosing the best management alternative of those considered still led to discounted costs exceeding discounted incomes, or put another way, the guiding rates of return could not be realized in such situations.

If the assumption of active management is dropped, two other alternatives remain. One might elect simply to pay the necessary annual management costs indefinitely, perhaps using the land only for public relations or recreational purposes, without anticipating any dollar returns. If the firm's goal were profit maximization, however, such a management regime could not be justified, for the present worth of these management costs is always greater than the loss-minimizing costs of the optimal active management program. The second and better alternative, given such a firm objective, would be to give up ownership of the land and invest the recovered capital elsewhere.

GENERAL CONCLUSIONS

Given our model and assumed values, it is evident that most red alder stands should be converted to Douglas-fir, and most of them immediately. The more profitable red alder management opportunities are generally concentrated on the poorer sites, in older existing alder stands, and under high conversion costs and low stumpage values.

IMPORTANCE OF THE INDIVIDUAL VARIABLES

The pattern of R's in table 7 illustrates the influence of individual variables on the retain or replace decision. Although there are interactions among the yield, cost, and price assumptions, general trends are readily apparent. Accordingly, the variables can be ranked in terms of their relative influence as follows:

Guiding Rate of Return

Red alder management is favored only under the most extreme cost and price assumptions when a 3-percent discount rate is used. As the rate increases, retaining red alder is sometimes preferred simply because returns from Douglas-fir are discounted over a greater number of years. This is especially noticeable on medium sites under the most pessimistic assumptions (lower right), where costs of conversion cannot be postponed long enough to offset the heavily discounted returns anticipated from Douglas-fir. The critical role of the guiding rate of return suggests that its determination deserves expert attention: a rule-of-thumb approach is clearly inappropriate.

Site Class

A quick glance at the table shows that red alder management is most often suggested on the poorest sites. This results from the site class equivalents and physical yield schedules that have been assumed: as the site improves, the productivity of Douglas-fir increases more quickly than the productivity of red alder. The advantages of conversion, therefore, are greatest on the best sites.

Stumpage Prices

To evaluate the importance of changing stumpage prices, it is necessary to compare certain pairs of table entries: the uppermost entries assume a high level of prices, the middle entries assume medium prices, and the lowest entries assume relatively low prices. High and medium prices lead to nearly identical retain or replace recommendations. However, the lowest stumpage price levels result in a marked increase in the number of recommendations to retain red alder, especially on the poorer sites at high discount rates.

This is primarily due to the changing price differentials between species assumed at the different price levels. Notice (in table 6) that Douglas-fir (clearcut) sawtimber is favored over red alder sawtimber by $48 per thousand board feet at the medium price level but only by $18.50 per thousand board feet at the lowest level.

A less important reason why Douglas-fir is favored by higher prices lies in the assumption that prices of the two species move together. As an increase in red alder prices increases the present value of future rotations, it also (to a lesser extent) increases the value of immediately liquidating the present red alder stand. In contrast, an increase in Douglas-fir prices favors only conversion. On balance, then, any increase in the price levels of both species at the rates built into our assumptions will increase the relative desirability of conversion.

Table 7.--*Optimal number of years to wait*

Red alder/ Douglas-fir site classes	Present age of red alder stands (years)	Guiding rate of return								
		3 percent			6 percent			9 percent		
		High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs
		Years to wait								
HIGH STUMPAGE PRICES AND LOW ANNUAL MANAGEMENT COSTS										
70/IV	15	20	0	0	20	20	10	20	20	10
	25	10	0	0	10	10	0	10	10	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0
	65	0	0	0	R	R	**0**	R	R	**R**
90/III	15	0	0	0	20	10	0	20	10	10
	25	0	0	0	10	0	0	10	0	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	R	**R**	**0**
110/II	15	0	0	0	0	0	0	10	0	0
	25	0	0	0	0	0	0	0	0	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	**R**	**0**	0
MEDIUM STUMPAGE PRICES AND LOW ANNUAL MANAGEMENT COSTS										
70/IV	15	20	0	0	20	20	10	30	20	10
	25	10	10	0	10	10	0	20	10	0
	35	0	0	0	0	0	0	10	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	R	0	0	R	0	0
	65	0	0	0	R	R	**0**	R	R	R
90/III	15	0	0	0	20	10	10	20	20	10
	25	0	0	0	10	0	0	10	10	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	**0**	0	0	R	R	**0**
110/II	15	0	0	0	0	0	0	20	10	0
	25	0	0	0	0	0	0	10	0	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	**R**	**0**	0
LOW STUMPAGE PRICES AND LOW ANNUAL MANAGEMENT COSTS										
70/IV	15	R	20	0	R	R	20	R	R	20
	25	R	10	0	R	R	10	R	R	10
	35	R	0	0	R	R	0	R	R	0
	45	R	0	0	R	R	0	R	R	0
	55	R	0	0	R	R	0	R	R	0
	65	R	0	0	R	R	R	R	R	R
90/III	15	20	0	0	R	20	10	R	R	20
	25	10	10	0	R	10	0	R	R	10
	35	0	0	0	R	0	0	R	R	0
	45	0	0	0	R	**0**	0	R	R	0
	55	0	0	0	R	R	0	R	R	R
110/II	15	0	0	0	20	20	0	R	R	10
	25	0	0	0	10	10	0	R	**R**	0
	35	0	0	0	0	0	0	R	**R**	0
	45	0	0	0	R	0	0	R	R	**0**

NOTE: An "R" means that red alder should be managed in perpetuity. Entries in bold type indicate "borderline" cases (see discussion in section "A General Sensitivity Analysis"). Entries within blocks are recommendations for loss-minimizing courses of action.

[1] Stumpage prices and management costs are taken from table 6; alternative costs of conversion are defined in table 4.

before converting red alder to Douglas-fir 1/

HIGH STUMPAGE PRICES AND HIGH ANNUAL MANAGEMENT COSTS

Red alder/ Douglas-fir site classes	Present age of red alder stands (years)	Yielding rate of return: 3 percent			6 percent			9 percent		
		High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs
70/IV	15	20	10	0	20	20	10	20	20	10
	25	10	10	0	10	10	0	10	10	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0
	65	0	0	0	0	0	**0**	R	0	**R**
90/III	15	0	0	0	20	10	0	20	10	10
	25	0	0	0	10	0	0	10	0	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	**0**	0	0	R	**R**	**0**
110/II	15	0	0	0	0	0	0	10	10	0
	25	0	0	0	0	0	0	0	0	0
	35	0	0	0	0	0	0	**R**	**0**	0
	45	0	0	0	0	0	0	R	R	**0**

MEDIUM STUMPAGE PRICES AND HIGH ANNUAL MANAGEMENT COSTS

70/IV	15	20	20	0	30	20	10	30	20	10
	25	10	10	0	20	10	0	20	10	0
	35	0	0	0	10	0	0	10	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	R	0	0	R	0	0
	65	0	0	0	R	R	**R**	R	R	R
90/III	15	0	0	0	20	20	0	20	20	10
	25	0	0	0	10	10	0	10	10	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0
	55	0	0	0	**R**	0	0	0	R	**0**
110/II	15	0	0	0	0	0	0	20	10	0
	25	0	0	0	0	0	0	10	0	0
	35	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	R	**0**	0

LOW STUMPAGE PRICES AND HIGH ANNUAL MANAGEMENT COSTS

70/IV	15	R	20	0	R	R	10	R	**R**	20
	25	R	10	0	R	R	0	R	R	10
	35	R	R	0	R	R	R	R	R	R
	45	R	0	0	R	R	0	R	R	R
	55	R	0	0	R	R	R	R	R	R
	65	R	**0**	0	R	R	R	R	R	R
90/III	15	20	0	0	R	20	10	R	R	R
	25	10	10	0	R	10	0	R	R	10
	35	0	0	0	R	0	0	R	R	0
	45	0	0	0	R	R	0	R	R	0
	55	0	0	0	R	R	0	R	R	R
110/II	15	0	0	0	R	R	0	R	R	10
	25	0	0	0	**R**	R	0	R	R	0
	35	0	0	0	**R**	0	0	R	R	0
	45	0	0	0	R	0	0	R	R	**0**

See "Note" and [illegible]

Present Age of Red Alder Stand

Even when prices are high and costs low, retaining red alder is sometimes indicated when the present red alder stand is in the oldest age class provided for this species. Under our assumptions, stands must be cut by 65 years of age on poor sites, 55 years on medium sites, and 45 years on good sites. If, at the time the retain or replace decision is made, the existing stand must be cut, conversion will often be undesirable because it is not possible to discount the major costs of conversion.

At the other extreme, it is frequently desirable to hold very young stands until they reach 25 or 35 years before replacing them. Such a delay is an expression of the relationship between the rate of increase in red alder yields with stand age and the rates of decrease in present values of both conversion costs and Douglas-fir returns as the discounting period lengthens. In the latter case, our assumption that site preparation costs disappear at age 30 is also important. It is noteworthy that on the best sites, where stands mature soonest, delays in conversion are seldom suggested.

Costs of Conversion

For each site, high costs of conversion more often lead to delays in replacing red alder than do lower costs. This is particularly apparent when the lowest stumpage prices are assumed.

Annual Management Costs

Annual management costs have little effect on the retain or replace decision. Contrasting the left-hand entries with those on the right reveals only a slight increase in the number of R's as management costs increase.

Although this basic table of results is strictly applicable only when our assumptions hold, the general influences noted and discussed above have far wider implications. For example, given any set of conditions, holding all the yields, prices, and costs constant while increasing the discount rate will favor retaining red alder. Similarly, possible minor changes in annual property taxes would not have as much effect on the desirability of conversion as would incorrectly estimated site classes.

EVALUATING THE STUDY ASSUMPTIONS

In this section, the basic calculations have been supplemented with a series of sensitivity analyses that suggest which study assumptions are critical and which can be violated without affecting the major conclusions of the study. Such information should help a forest manager judge the applicability of the study to his particular case.

A GENERAL SENSITIVITY ANALYSIS

A refinement in the analysis enables one to determine which retain or replace recommendations will be reversed if our assumed costs, prices, and yields are changed appreciably. Such an approach sheds considerable light on the stability of the findings and thereby helps put them in their proper perspective. In table 7, boldface type indicates when a 10-percent or smaller change in a calculated present worth will alter the decision to manage red alder or to convert to Douglas-fir.

Consider, for example, the R in the bottom row of the medium-price and low-cost section of table 7. If our assumptions concerning red alder have been too optimistic by 10 percent, or those concerning Douglas-fir too pessimistic by 10 percent, the stand should be converted rather than held in red alder (the detailed calculations for this problem are presented in Appendix B). Similarly, the adjacent boldfaced zero implies that changes favoring red alder by 10 percent would reverse that decision.

The scarcity of these borderline decisions suggests that the general conclusion presented earlier is still valid: under most feasible programs of active management, most red alder stands should be converted to Douglas-fir.

RELATIVE CHANGES IN STUMPAGE PRICES

In the previous section, it was assumed that future red alder and Douglas-fir prices would move up or down together. In table 8, the results of a few instances where such a relationship does not hold are explored.

There are very few shifts toward red alder management if price schedule A (the high prices of table 7) is replaced by schedule B, which is much less favorable to Douglas-fir. However, a slight further reduction in Douglas-fir prices to those of schedule C (the low prices of table 7) sharply favors retaining red alder. The conversion decision is apparently insensitive to red alder price changes under the investigated conditions: the 80-percent drop in red alder prices between schedules B and C, which would be expected to favor conversion, is overshadowed by the more modest decrease in Douglas-fir prices.

THE EQUIVALENCE OF RED ALDER AND DOUGLAS-FIR SITES

Another question that might be raised concerns the assignment of Douglas-fir site classification to lands presently supporting only red alder. Our general assumption is that any particular site can be rated as poor, fair, or good for both species. [5]

[5] *In contrast to our assumptions of site class equivalents of 70/IV, 90/III, and 110/II, Smith (1967, p. 274) reports that Schon found the equivalents in British Columbia to be 57/IV, 73/III, and 90/II. The analyses in this paper, then, are somewhat more favorable towards red alder. Also, see footnote on page 3.*

Table 8.--*Optimal number of years to wait before converting red alder to Douglas-fir, under three guiding rates of return and several stumpage price assumptions*[1/]

Red alder/ Douglas-fir site classes	Present age (years) of red alder stands	3-percent rate of return and stumpage prices[2/]			6-percent rate of return and stumpage prices[2/]			9-percent rate of return and stumpage prices[2/]		
		A $7.50/$21 $55/$70	B $7.50/$21 $20/$30	C $1.50/$4 $18/$22.50	A $7.50/$21 $55/$70	B $7.50/$21 $20/$30	C $1.50/$4 $18/$22.50	A $7.50/$21 $55/$70	B $7.50/$21 $20/$30	C $1.50/$4 $18/$22.50
70/IV	15	20	20	R	20	20	R	20	20	R
	25	10	10	R	10	10	R	10	10	R
	35	0	0	R	0	0	R	0	0	R
	45	0	0	R	0	0	R	0	0	R
	55	0	R	R	0	R	R	0	0	R
	65	0	R	R	R	R	R	R	R	R
90/III	15	0	20	20	20	20	R	20	20	R
	25	0	10	10	10	10	R	10	10	R
	35	0	0	0	0	0	R	0	0	R
	45	0	0	0	0	0	R	0	0	R
	55	0	0	0	0	R	R	R	R	R
110/III	15	0	0	0	0	20	R	10	20	R
	25	0	0	0	0	10	R	0	10	R
	35	0	0	0	0	0	R	0	0	R
	45	0	0	0	0	R	R	R	R	R

NOTE: An "R" means that red alder should be managed in perpetuity.

[1/] High annual management costs ($1.60 per acre for Douglas-fir, $1 per acre for red alder) and high costs of conversion (as in table 4) are assumed.

[2/] Stumpage prices are read, for example, as "Schedule A red alder: $7.50 per cord and $21 per M bd. ft.; Douglas-fir: $55 per M bd. ft. for thinnings and $70 per M bd. ft. for final harvests.

For determination of the significance of the effect of the site equivalence assumptions on our retain or replace recommendations, it is useful to calculate a value for each Douglas-fir site class. All thinning volumes in the basic yield table (Appendix A, table 14) were multiplied by 0.78, the average ratio of thinning-to-clearcut prices (table 6), to convert them to clearcut equivalents. Discounting the individual yields and summing them gives the discounted volumes of table 9. Since all assumed stumpage prices are constant over time, the present value of future rotations may be calculated by multiplication of these discounted volumes by any price per thousand board feet of clearcut stumpage that is appropriate (Lundgren 1966, p. 6). The important point here is that the relative advantage of one Douglas-fir site class over another can be exactly expressed without worry about prices. Further, since the discounted volumes are all for a common year (the conversion year), they reflect relative values even if there is a 10- or 20-year delay before conversion.

The pattern of relative values is clear. Good sites, of course, are worth more than poor sites. However, as the discount rate increases so that still more emphasis is placed on early returns, the best sites quickly increase their relative advantage.

What is the effect of assuming a lower than justified Douglas-fir site class for ground now supporting red alder? Any dollar advantage of conversion to Douglas-fir will appear smaller than it really is, and red alder will be retained too often. The upper part of table 10 shows that this would sometimes occur if an assumed 70/IV equivalence should have been 70/III. The difference in value between Douglas-fir yields produced by site III and by site IV is, in these instances, greater than the difference between present net worths of retaining red alder and replacing it with Douglas-fir, if site IV productivity is assumed.

What is the effect on the conversion decision if a higher than justified Douglas-fir site class were assumed? Conversion would be suggested more often than warranted. The lower part of table 10 shows the direction of changes that would be required in our recommendations in the case of an error as just hypothesized. Because the adjusted entries would be based on a 90/IV site equivalence, there would be more R's than in the (original) upper table, which is based on a 70/IV site equivalence, somewhat less favorable to red alder.

Table 9.--*Discounted volumes per acre*[1/] *produced by a continuous series of Douglas-fir rotations*[2/]

Guiding rate of return (percent)	Douglas-fir site class		
	IV	III	II
3	4.7	10.9	19.9
6	.7	2.2	4.7
9	.1	.7	1.6

[1/] Thinning yields were multiplied by 0.78 and harvest yields by 1.00, the products were discounted to the beginning of the rotation and summed, and the sum was adjusted for a continuous series of rotations.

[2/] Based on appendix table 14.

Table 10.--Conversion recommendations that would be changed if the estimated productivity of Douglas-fir on a given red alder site were changed[1]

(Number of years to wait[2])

Red alder/ Douglas-fir site class	Present age (years) of red alder stand	Guiding rate of return								
		3 percent			6 percent			9 percent		
		High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs	High conversion costs	Medium conversion costs	Low conversion costs
		If a red alder site 70 is actually a Douglas-fir site III rather than IV, the shaded R's should be numbers--convert to Douglas-fir								
70/IV	15	**R**	20	0	R	R	20	R	R	20
	25	**R**	10	0	R	R	10	R	R	10
	35	**R**	0	0	R	R	0	R	R	0
	45	**R**	0	0	R	R	0	R	R	0
	55	**R**	0	0	R	R	**R**	R	R	R
	65	**R**	0	0	R	R	**R**	R	R	R
		If a red alder site 90 is actually a Douglas-fir site IV rather than III, the shaded numbers should be R's--do not convert to Douglas-fir								
90/III	15	**20**	**0**	0	R	**20**	**10**	R	R	20
	25	**10**	10	0	R	**10**	**0**	R	R	10
	35	**0**	0	0	R	**0**	0	R	R	0
	45	**0**	0	0	R	R	**0**	R	R	0
	55	**0**	**0**	0	R	R	**0**	R	R	R

NOTE: Shaded recommendations would be reversed if an error were made in estimation of Douglas-fir site productivity.

[1] Table entries were extracted from table 7; conversion cost levels are defined in table 4; the high management costs and low prices are defined in table 6.

[2] Before conversion of red alder to Douglas-fir. An "R" means that red alder should be managed in perpetuity.

At several earlier points in this paper, it was noted that the retain or replace decision is most sensitive at the lower stumpage price levels. For this reason, the forecasting of Douglas-fir productivity is most critical when future prices are expected to be low relative to future costs. Any assumptions other than the high costs and low prices of table 10 lead to fewer changes in the retain or replace decision when site equivalents are varied.

CONTRASTING DOUGLAS-FIR MANAGEMENT WITH AND WITHOUT THINNING

To explore the impact of thinning Douglas-fir stands on the conversion decision, we have adopted a yield table for unthinned stands (Appendix A, table 15). The conversion decision is not particularly sensitive to the decision to thin. It is true that differences in present worths between Douglas-fir and red alder are substantially increased if a thinning regime is assumed, but the preferred time of replacement is unaffected in most cases shown in summary table 7 if thinning incomes are eliminated.

When both stumpage prices and conversion costs are either high or low, recommendations on conversion do not differ much between the two styles of management, i.e., with or without Douglas-fir thinnings. Similarly, few changes occur under high prices and low cost assumptions with the elimination of fir thinnings. On the other hand, as we have noted before, when both prices and costs are unfavorable, the conversion decision is quite sensitive to reductions in Douglas-fir value yields. The trend away from Douglas-fir management when the value yields are reduced by elimination of thinnings is summarized in table 11.

THE INFLUENCE OF TAXES

A shortcoming of our analytical model for some readers will be its failure to consider the effect of taxes on the conversion decision. Our rationale is simply that this expense is unique to each individual or firm ownership situation, depending upon such factors as its taxable income bracket and the composition of its business (Williams 1964, 1967).

Due to differences in the form of taxation ordinarily employed at the Federal, State, and local levels, such taxes may each be expected to have different effects on forest management in general and on the choice between Douglas-fir and red alder management in particular. The tax impact may even be great enough to alter the conversion decision.

In respect to the Federal income tax, since we have included more initial costs in the relatively intensive management programs of Douglas-fir, a large share of such costs would have to be capitalized and therefore could not be written off before the end of the rotation. This would constitute a disadvantage for the Douglas-fir management regime relative to the red alder. On the other hand, annual management costs can be expensed against other firm incomes subject to taxation yearly; hence the impact of such out-of-pocket costs ordinarily would tend to be reduced, thereby favoring Douglas-fir over red alder.

Table 11.--*Optimal number of years to wait before converting red alder to Douglas-fir when Douglas-fir management does and does not include thinnings*[1/]

Red alder/ Douglas-fir site class	Present age (years) of red alder stand	Guiding rate of return					
		3 percent		6 percent		9 percent	
		Thinning	No thinning	Thinning	No thinning	Thinning	No thinning
70/IV	15	20	20	30	R	30	R
	25	10	10	20	R	20	R
	35	0	0	10	R	10	R
	45	0	0	0	R	0	R
	55	0	0	R	R	R	R
	65	0	0	R	R	R	R
90/III	15	0	20	20	20	20	R
	25	0	10	10	10	10	R
	35	0	0	0	0	0	R
	45	0	0	0	R	0	R
	55	0	0	R	R	R	R
110/II	15	0	0	0	R	20	R
	25	0	0	0	R	10	R
	35	0	0	0	R	0	R
	45	0	0	0	R	R	R

NOTE: An "R" means that red alder should be managed in perpetuity.

[1/] High annual management costs and medium stumpage prices (see table 6) and high costs of conversion (see table 4) are assumed. Yields without thinning are presented in Appendix A as table 15.

In contrast, the effects of the Federal income tax rate alone tend to favor the lower valued red alder. This is the reason: in our basic analysis, we ascribed the importance of stumpage price levels, as they influence the retain or replace decision, primarily to the assumed price differentials between species. If stumpage revenues are subject to, say, a 25-percent capital gains tax, then these relative differentials between species will be reduced and in the direction of delaying conversion or retaining red alder. For example, in table 6 the price differential in favor of Douglas-fir for clearcut sawtimber drops from $49 to $36.75 at the highest level of prices and from $18.50 to $13.88 at the lowest level.

It may occasionally be possible to adapt our before-taxes analysis to making the equivalent of after-tax comparisons. For instance, our "low level" costs might be about the same as the reader's after-taxes "high level" costs. In addition, one of the sensitivity analyses might suggest which differences are most likely to be critical. If neither of these approaches is adequate, computer programs, available on request to this Station, can be used to make specialized analyses.

SCHEDULING STAND CONVERSION

When we turn from considering stands in isolation to the problem of scheduling the conversion of a large number of stands, we often find that the recommended time of conversion cannot be followed.

A hypothetical management unit of red alder stands grouped into six stand categories (A through F) is presented in table 12. Site indexes and age classes are as indicated, high management and conversion costs and high stumpage prices (tables 4 and 6) are assumed, and a 6-percent guiding rate of return is considered.

Each entry in the fifth column of the table expresses the advantage of converting a particular red alder stand to Douglas-fir. For instance, to convert a 25-year-old category B stand would be foolish, for the stand is worth $47.19 per acre more as red alder. If the stand were kept in red alder until age 35, however, and then liquidated and replaced with Douglas-fir, the landowner would be ahead by $37.63 per acre, in terms of dollars discounted to the present. Further delays in conversion would be expensive: waiting another 10 years until age 45 would reduce the conversion advantage on each acre from $37.63 to $23.80, a loss of $13.83.

So long as it is possible to convert the red alder stands to Douglas-fir at the times of greatest advantage, the forest manager is assured of earning the highest possible return from the land. Moreover, the positive conversion advantages assure that any out-of-pocket capital investments required for conversion would earn at least the 6 percent assumed as the guiding rate of return.

Given that red alder stands are to be replaced with Douglas-fir and the optimal times of replacement are known, budget and manpower limitations may force postponing some conversion beyond the most advantageous time. The problem becomes one of setting priorities. In the sixth column of table 12, the priorities reflect the relative sizes of the conversion advantages. If, for example, just two categories of stands were to be converted every 10 years, conversion could most advantageously be carried out as shown in the last column.[6] The cost of this constraint on conversion can be calculated if the differences between the optimal and the realized conversion advantages are weighted by the number of acres in each stand category and summed. Whether the reasons for such a limitation on conversion could justify this cost would be a fundamental policy question in a firm's operations.

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[6] *This is true because the sum of the conversion advantages that would be realized exceeds the sum of all other possible combinations of conversion advantages. Where more categories of stands or more complex constraints must be considered, some type of mathematical programing analysis might be required to determine the optimal schedule.*

Table 12.--*Illustrative priorities in scheduling conversion of red alder stands to Douglas-fir*

Hypothetical stand category	Red alder site index	Present age of stand	Possible conversion ages	Possible conversion advantages	Conversion priority	Time of conversion
		Years	*Years*	*Dollars per acre*		
A	70	15	15	-119.80		
			25	-26.36		In 20 years
			35	1/ 21.01	6	
B	70	25	25	-47.19		
			35	1/ 37.63	5	In 10 years
			45	23.80		
C	70	35	35	1/ 67.38	3	
			45	42.62		In 10 years
			55	8.63		
D	90	15	15	-4.89		
			25	42.04		In 20 years
			35	1/ 56.08	4	
E	90	35	35	1/ 179.86	2	
			45	76.76		Now
			55	5.31		
F	110	25	25	1/ 220.02	1	
			35	150.84		Now
			45	51.73		

1/ Conversion advantage at optimal conversion age.

CONCLUDING COMMENTS

It is again stressed that the assumptions, including both particular values and relationships among variables (e.g., future prices will rise or fall together), imply definite limitations on the applicability of the analysis. Certainly, the reader should thoroughly understand the procedures that have been employed before relying heavily on the results. However, we feel that those managers who can furnish their own experience data will likely find the general model an appropriate guide for analyzing red alder conversion problems.

The basic analysis clearly showed that it would be advantageous to convert red alder to Douglas-fir in most instances, and to do it now. Why, then, aren't more forest managers rushing to convert their stands? A few of the many possible answers are:

1. Managers may be partially or wholly unaware of the potential advantages of conversion.

2. Owners may prefer a passive type of management consisting of simply holding their red alder stands:

a. in preference to liquidating their investment and incurring a tax liability;

b. on the speculation that alder stumpage prices will increase significantly in the not too distant future;

c. in preference to actively seeking out markets for the alder since these markets are not as general or as active as the markets for conifers;

d. with the thought that more valuable coniferous species will eventually win control of the site without any help; or

e. on a speculative basis, reasoning that the land will soon be too valuable for other uses to consider any forest management schemes requiring capital investments.

3. The average ownership might be of low-site red alder stands, with little potential for supporting Douglas-fir.

4. Red alder markets and prices may not be as strong throughout the region as assumed.

5. Conversion costs may actually be higher than assumed.

It will be recalled that red alder management was generally recommended when sites were poor, stumpage prices low, and costs high. This is the combination of factors where very little capital can be generated by liquidating the existing alder stand, but it is also the combination which requires the highest capital investments in conversion to Douglas-fir. Staying with red alder and avoiding out-of-pocket costs is much more attractive. However, under somewhat more favorable conditions (better sites, higher stumpage prices, and lower costs), much of the capital necessary for establishing Douglas-fir might be internally accumulated by a delay of the conversion for 10 or 20 years. And under the best conditions (good site, low costs, and high prices), the income generated from harvesting the existing red alder stand plus the promise of a substantial return on investment from a new Douglas-fir stand are enough to suggest immediate conversion.

If one adds a high guiding rate of return to the set of circumstances outlined above as favoring alder retention, retention still tends to be recommended, but not because of high costs of conversion. Instead, the high cost of holding Douglas-fir growing stock on the stump (forest capital) now rules in favor of the alder.

Some readers might be concerned about the general implications of this study for the red alder industry of the Pacific Northwest. If alder stands were to be replaced by Douglas-fir on all ownerships to the extent we have suggested would be profitable, severe adjustments could be expected. But several factors make such a drastic change unlikely.

First, if alder conversion were begun on a large scale, the abundance of red alder offered for sale would quickly drive down stumpage prices. The immediate advantage of conversion would be reduced (although, in the long run, such an increase in supply might well generate its own demand).

Perhaps of greater importance is the apparent slowness of investors to respond to profitable investment opportunities in forestry. Moreover, it appears that a large share of private forest owners do not respond at all. This suggests that, since most of the better red alder sites are privately owned, a large share of the future supply of such timber is likely to continue to be produced in spite of the greater profits available from converting to Douglas-fir management.

Given these factors working against conversion plus the occasions where red alder management is advantageous, a great reduction in the future red alder supply does not appear likely, even in the long run. In fact, since a large share of the present alder acreage is in the younger age classes, some increase in supply could be expected in the next several decades even if most forest owners were to respond to the investment opportunities suggested by this study.

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APPENDIX A

ASSUMED PHYSICAL YIELD TABLES

The red alder physical yields assumed in this study are given in table 13 and the calculated value yields in table 3 (p. 4).

Table 13.--*Expected red alder yields from clearcutting*[1/]

Age of stand (years)	Red alder/Douglas-fir site classes					
	70/IV		90/III		110/II	
	Pulpwood	Sawtimber	Pulpwood	Sawtimber	Pulpwood	Sawtimber
	Cords	*M bd. ft.*	*Cords*	*M bd. ft.*	*Cords*	*M bd. ft.*
15	5.22	0	10.00	0	14.66	0
25	16.66	0	25.55	0	34.44	0
35	25.78	0	38.89	0	13.11	13.28
45	32.78	0	10.55	13.68	9.11	21.52
55	9.44	9.60	7.00	19.20	--	--
65	6.44	12.08	--	--	--	--

[1/] Yields developed from tables 6, 11, 12, and 13 in Worthington et al. (1960). Conventions used in the derivation are:

a. yields are 80 percent of tabled values;

b. 1 cord = 72 cubic feet;

c. in stands where d.b.h. of the average tree is less than or equal to 10.5 inches, only pulpwood is produced;

d. in stands where d.b.h. of the average tree is greater than 10.5 inches, just pulpwood is produced by trees 9.5 inches in d.b.h. and smaller and just sawtimber by larger trees.

Physical yields with thinnings assumed for Douglas-fir management are shown in table 14. These yields were synthesized from both published and unpublished data from plantations in the Pacific Northwest and elsewhere. Compared with yields of natural stands that have not been thinned, e.g., Worthington and Staebler (1961), these synthesized yields might appear to be optimistic. It should be remembered, however, that these estimates are for future managed stands rather than for wild stands on which normal yield tables are based. The authors are of the opinion that genetic improvements in planting stock and improvements in planting and seeding techniques will improve both survival and

growth rates, even over that found in existing plantations. In addition, the increasing utilization of smaller materials and a large proportion of all raw materials being processed promises an increased merchantable yield from all stands.

Table 14.--*Expected Douglas-fir yields from thinnings and final harvests*

Stand age (years)	Red alder/Douglas-fir site classes		
	70/IV	90/III	110/II
	M bd. ft. per acre[1/]		
25	0	2.3	9.7
40	3.3	12.5	17.1
55	5.4	13.4	20.5
70	11.0	14.2	51.8
85	7.8	33.2	--
100	23.9	--	--

[1/] International rule, 1/4-inch kerf. All trees 6.6 inches and larger d.b.h. to a minimum top diameter of 5 inches. In each column, all yields are thinnings except the bottom one, which is the final yield for a rotation in that site class.

Physical yields to be expected from Douglas-fir management without thinnings are given in table 15.

Table 15.--*Expected Douglas-fir yields without thinning*

Stand age (years)	Red alder/Douglas-fir site classes		
	70/IV	90/III	110/II
	M bd. ft. per acre[1/]		
25	0	0	0
40	0	0	0
55	0	0	0
70	0	0	80.5
85	0	[2/]74.2	--
100	52.6	--	--

[1/] International rule, 1/4-inch kerf. All trees 6.6 inches and larger d.b.h. to a minimum top diameter of 5 inches. From table 33, p. 117, of Worthington and Staebler (1961).

[2/] Linear interpolation between volumes of 80- and 90-year-old stands.

APPENDIX B

CALCULATION OF A SAMPLE PROBLEM

The following exercise was included to clear up as many ambiguities as possible in the descriptions of the calculating procedures used in this study.

We have chosen to illustrate our procedures by presenting the detailed calculations necessary to solve a conversion problem; the resulting recommendations are presented as part of table 7. This particular problem is based on the best site class, a 9-percent discount rate, high conversion costs, medium stumpage prices, and low management costs. Costs and prices were taken from tables 4 and 6 and value yields from tables 3 and 5. The following calculations, which are necessary to contrast the value of retaining red alder to that of immediately converting a 15-year-old stand, consider all of the elements outlined in table 1 (inside front cover) and precisely follow the equations presented in the section entitled "The Analytical Model and Assumptions."

The Present Net Worth of Retaining Red Alder

$$\left[\begin{array}{c}\text{Present value of}\\ \text{perpetual series}\\ \text{of red alder yields}\end{array}\right] = (299.23)\left[\frac{(1.09)^{45}}{[(1.09)^{45}-1]\,(1.09)^{45-15}}\right]$$

$$= \$23.03$$

$$\left[\begin{array}{c}\text{Present value of}\\ \text{annual red alder}\\ \text{management costs}\end{array}\right] = (0.50)\left[\frac{1}{0.09}\right]$$

$$= \$5.56$$

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of retaining}\\ \text{red alder}\end{array}\right] = \$23.03 - \$5.56 = \boxed{\$17.47}$$

The Present Net Worth of Replacing Red Alder With Douglas-Fir

$$\left[\begin{array}{c}\text{Present value of}\\ \text{existing red}\\ \text{alder stand}\end{array}\right] = (66.01)\left[\frac{1}{(1.09)^{0}}\right]$$

$$= \$66.01$$

$$\left[\begin{array}{c}\text{Present value of}\\ \text{annual red alder}\\ \text{management costs}\end{array}\right] = (0.50)\left[\frac{(1.09)^0 - 1}{0.09(1.09)^0}\right]$$

$$= \$0.00$$

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of existing red}\\ \text{alder stand}\\ \text{BEFORE CONVERSION}\end{array}\right] = \$66.01 - \$0.00 = \$66.01$$

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of site preparation}\\ \text{costs at CONVERSION}\end{array}\right] = (70.00)\left[\frac{1}{(1.09)^0}\right]$$

$$= \$70.00$$

$$\left[\begin{array}{c}\text{Present value of}\\ \text{cost of periodically}\\ \text{establishing Douglas-fir}\end{array}\right] = (80.00)\left[\frac{(1.09)^{70}}{[(1.09)^{70} - 1](1.09)^0}\right]$$

$$= \$80.19$$

$$\left[\begin{array}{c}\text{Present value of}\\ \text{cost of periodic}\\ \text{brush control}\end{array}\right] = (40.00)\left[\frac{(1.09)^{70}}{[(1.09)^{70} - 1](1.09)^{0+5}}\right]$$

$$= \$26.06$$

$$\left[\begin{array}{c}\text{Present value of}\\ \text{annual Douglas-fir}\\ \text{management costs}\end{array}\right] = (0.60)\left[\frac{1}{0.09(1.09)^0}\right]$$

$$= \$6.67$$

$$\left[\begin{array}{c}\text{Present value of}\\ \text{perpetual series of}\\ \text{Douglas-fir yields}\end{array}\right] = \left[\frac{(1.09)^{70}}{[(1.09)^{70} - 1](1.09)^0}\right]\left\{\left[\frac{436.50}{(1.09)^{25}}\right] + \left[\frac{769.50}{(1.09)^{40}}\right] + \left[\frac{922.50}{(1.09)^{55}}\right] + \left[\frac{3,180.00}{(1.09)^{70}}\right]\right\}$$

$$= \$90.86$$

$$\left[\begin{array}{c}\text{Present net worth of}\\ \text{perpetual Douglas-}\\ \text{fir management}\\ \text{AFTER CONVERSION}\end{array}\right] = \$90.86 - \$80.19 - \$26.06 - \$6.67 = -\$22.06$$

$$\left[\begin{array}{c}\text{Present net worth}\\ \text{of converting red}\\ \text{alder to Douglas-fir}\end{array}\right] = \$66.01 - \$70.00 - \$22.06 = \boxed{-\$26.05}$$

These calculations lead to the two boxed figures, the present worths of retaining red alder and of replacing it immediately with Douglas-fir. The first is entered in the fourth column of table 16 and the other in the third column. Since the options of waiting 10, 20, or 30 years before conversion must also be considered, it is necessary to run through three more series of calculations and add the present worths of delayed conversions to column 3. Now it becomes obvious that if one is going to convert to Douglas-fir, it should be done in 20 years, at age 35. Comparing this present worth to that of retaining red alder indicates that the stand should be converted. The positive conversion advantages of the fifth column are simply the differences between the values in columns 3 and 4.

Repeating these types of calculations for the different present stand ages led to the recommendations in the last column. Notice the negative conversion advantage for a 45-year-old stand. This indicates that red alder should be retained. Since a 10-percent change in either of the present worths of retaining red alder or converting to Douglas-fir could change the conversion advantage to a positive value, this is a "borderline" case as defined in the section entitled "A General Sensitivity Analysis." Therefore, the corresponding R appears in boldface type in the bottom row of the medium-price and low-cost section of table 7.

The time-consuming nature of calculations like these that were required for our analysis led to the development of specialized computer programs (see footnote 2, p. 2).

Table 16.--*Summarizing the calculations necessary to decide whether a single red alder stand should be converted to Douglas-fir*[1/]

Present age of red alder stand	Age when conversion is possible	Present worth of conversion to Douglas-fir	Present worth of retaining red alder	Advantage of conversion to Douglas-fir	Recommendation
Years		*Dollars per acre*			
15	15	-26.05			Convert in 20 years
	25	23.37			
	35	30.41	17.47	12.94	
	45	15.75			
25	25	62.92			Convert in 10 years
	35	79.59	48.96	30.63	
	45	44.89			
35	35	196.02	123.51	72.51	Convert now
	45	113.87			
45	45	277.17	300.00	-22.83	Retain red alder

[1/] Reported in table 7. Assumptions are a red alder/Douglas-fir site class of 110/II, a 9-percent guiding rate of return, medium stumpage prices, and low annual management costs (as defined in table 6), and high conversion costs (table 4).

Yoho, James G., Chappelle, Daniel F., and Schweitzer, Dennis L.
1969. The economics of converting red alder to Douglas-fir
USDA Forest Service Res. Pap. PNW-88, 31 pp.
Pacific Northwest Forest & Range Experiment Station,
Portland, Oregon.

This study defines those conditions where it is more profitable to replace red alder stands with Douglas-fir than to manage for red alder. Under most of the circumstances analyzed, red alder stands should be immediately converted. In order of importance, the critical variables in this decision were found to be the discount rate, site productivity, expected stumpage prices, the present age of the existing red alder stand, costs of conversion, and annual management costs. Sensitivity analyses suggest how these variables influence the conversion decision.

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Timber Flows and Utilization Patterns in the Douglas-fir Region, 1966

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SUMMARY

Increasing demands on the Douglas-fir region's limited timber supply make it important that relationships between landownership classes, the forest industry, and the region's economy be better understood. Insight into the distribution of logs from stump to mill is a necessary first step in this process. In this study, the pattern of timber distribution from each landownership class and to each kind of mill is identified.

This material is presented in a context of economic areas based on commuting and shopping patterns with each area consisting of a county or group of counties. Each economic area's degree of dependency on employment in forest-based industries is identified for the purpose of pointing out the relative value of the timber industry and changing log supply sources to each area.

Ten of the region's 15 functional economic areas are cited as being highly dependent on employment in timber-based industries, with the Roseburg, Coos Bay, and Port Angeles areas being the most dependent. The Seattle area is the only area classified as being slightly dependent on employment in the timber industries.

The Eureka economic area is the region's largest log market, followed by the Eugene, Portland, Seattle and Coos Bay Areas, each consuming over 1 billion board feet of logs. Of the 13.7 billion board feet consumed within the region, the lumber industry used 58 percent, mainly in the Eureka, Portland, Eugene, Seattle and Coos Bay areas; the plywood industry used 30 percent, concentrated in the five areas from Corvallis to Medford; pulp plants consumed 11 percent, with the Seattle area the largest single consumer of pulp logs; and shake and shingle mills used 1 percent, mainly in the Aberdeen area.

Lumber is the region's leading forest industry measured in terms of number of plants and volume of wood used. The majority of the sawmill capacity is concentrated in three areas, Eureka, Eugene, and Portland. This pattern is true for all mill size classes except small mills which are concentrated in the Seattle and Tacoma areas. In general, the lumber industry has been more stable in western Washington but much larger in western Oregon and northwestern California.

Medium-sized sawmills are the heaviest users of Federal timber, and small mills and very large mills rely much more on private sources for their timber supply. The large mills obtain a very high proportion of their timber needs from their own lands; the small operator purchases his timber from other private sources.

The plywood industry is heavily concentrated in southwest Oregon and obtains over 50 percent of its timber needs from Federal lands. Veneer mills in particular use a high proportion of Federal timber, whereas the integrated veneer and plywood operations (producing both veneer and plywood) use private timber to a greater extent. This difference is due to the landowning characteristics of each type of operation.

Pulp plants are heavy users of private timber, most of which comes from company lands. Shake and shingle mills also count heavily on private logs — most of their supply is purchased from other private landowners.

Private logs are the most important source of supply for the entire region's forest industries. However, because of the geographical distribution of forest landownership in the region, private logs are more important to some economic areas and public logs to others. The greatest volume of private logs

was consumed by the Eureka area; but the Longview area, obtaining over 85 percent of its logs from private lands, was most reliant on this source. All but two areas, Roseburg and Medford, received over 40 percent of their timber needs from private lands. In total, 59 percent of the private logs in the region were consumed by the lumber industry, 25 percent by the plywood industry, 15 percent by the pulp industry, and 1 percent by shake and shingle plants.

The National Forest System supplied about a third of the logs used by the region's forest industry in 1966. The largest volume of National Forest logs, 763 million board feet, was consumed in the Eugene area; and it was also the Eugene area, along with the Medford area, that relied most heavily on these logs — both areas obtained just over 45 percent of their supply from this source.

The Willamette is the largest National Forest supplier, furnishing 890.6 million board feet, or 20 percent of total National Forest logs. Most of this Forest's logs go to the Eugene area, and over half of the logs are used by the plywood industry. The Gifford Pinchot and the Umpqua National Forests were the second and third largest suppliers, respectively, of National Forest timber.

Fifty-eight percent of the National Forest logs were used by the region's lumber industry, 37 percent by the plywood industry, 5 percent by pulp plants, and less than 1 percent by shake and shingle operations.

Markets served by the Willamette, Umpqua, Siskiyou, Klamath, and the Olympic National Forests are areas rated as dependent on timber-based employment. These areas have economies where wood, lumber, or pulp products are the primary means of supporting the local population. In other portions of the region, forest industries using National Forest logs are located in areas where the economy is more diversified and not nearly so dependent on wood-based manufacturing. Markets served by the Gifford Pinchot, Mount Hood, and Mount Baker National Forests fit this latter condition. Although in either case a given mill may be largely dependent on National Forest stumpage for its raw material supply, it is in those areas where National Forest timber supports the major part of the economy that Forest Service policy has its greatest economic impact.

The Bureau of Land Management supplied 1.1 billion board feet of timber in 1966, representing 8 percent of the total timber used. The Roseburg economic area was the largest user of these logs, 241.3 million board feet. The Bureau of Land Management's logs were used by the region's forest industry in the following manner: lumber industry, 54 percent; plywood plants, 45 percent; pulp plants, 1 percent.

The Bureau of Indian Affairs furnished less than 1 percent of the region's total log supply in 1966, with the major markets the Aberdeen and Eureka economic areas. The region's pulp plants used 31 percent of the logs sold by the Bureau of Indian Affairs.

State lands supplied 4.2 percent of the total log supply. The Tacoma area in Washington and the Coos Bay area in Oregon were the heaviest users of State logs, but State logs were most important to the forest industry in the Port Angeles area where 18.7 percent of the logs used were from State lands.

Fifty-two percent of the State logs were consumed by the region's lumber industry, 26 percent by the plywood industry, pulp plants used 20 percent, and about 2 percent were used by shake and shingle operations.

Intra-area log movements were shown to be limited, especially in the more timber-dependent areas. Nine of the region's 15 economic areas obtained at least 70 percent of their timber supplies from within their respective boundaries, and only one of the timber-dependent areas, Longview, obtained less than 60 percent of its log supplies from within its own borders. The Seattle area was the region's leading importer of logs, 632.8 million board feet, and Tacoma was the leading inter-area exporter, 599.0 million board feet.

Forest resources have played a major role in the region's past economic development and will continue to do so. Although timber is equally important to all the region's mills, the importance of timber to areas in the region varies according to each area's degree of dependency on timber-based employment.

INTRODUCTION

Objectives

Determining log flow patterns in the Douglas-fir region[1] is by necessity an early step in discovering relationships between timber landowners, the forest industry, and the region's economy. With this in mind, we have provided information on regional log flows for one point in time, 1966.

The distribution of plants and of plant capacities in 1966 is determined, and markets for logs are discussed in terms of specified areas in the region and plant types.[2] Where and what kinds of plants form the region's log markets and who is directly dependent on the various forest landownership classes for logs are answered in this report. All of these questions are considered within a framework of the region's dependency upon timber industry employment.

A consequence of the growing demand for timber and the rise in stumpage prices has been increasing pressure to intensify management on all forest lands. Land managing agencies are well aware that healthy timber industry and dependent communities are keys to the region's economic well-being. Data presented here on timber flows and log utilization patterns will provide decisionmakers with further insights into this complex situation. Forest managers will be in a better position to judge their sphere of influence on the forest industry and the region's economy; county and local officials will be better able to determine the relative strength of their forest industry; and local and regional planners can more adequately identify the mobility of the region's timber resource.

Economic development among communities within the 42-county Douglas-fir region has occurred at an uneven pace, and it must be recognized that realization of economic stability in a community is much more complex than that which is implied by sustained-yield forestry. Insights based on community growth and development are needed by private and public resource managers in order to cope with the emerging local problems associated with geographic shifts in timber-dependent industry and available timber supply. For this reason, the 42-county Douglas-fir region was divided on a geographical basis into 15 functional economic areas (fig. 1).

The 15 areas are essentially the commuting and shopping zones delineating local labor markets and service areas and are people-oriented rather than resource-oriented units. Each area represents a relatively self-contained unit with respect to commuting and shopping.[3]

These areas were derived from a special study[4] that was part of the "Douglas-fir Sup-

[1] *The Douglas-fir region is defined here as the 19 counties of western Washington, the 19 counties of western Oregon lying west of the Cascade Crest, and Del Norte, Siskiyou, Humboldt, and Trinity Counties in northern California.*

[2] *Log market throughout this paper is defined as the point of log utilization.*

[3] *For discussion see: Fox, Karl A., and Kumar, T. Krishna. Delineating functional economic areas.* In *Research and education for regional and area development. 287 pp., illus. Ames: Iowa State Univ. Press. 1967.*

[4] *Maki, Wilbur R., Schallau, Con H., and Beuter, John H. Importance of timber-based employment to the economic base of the Douglas-fir region of Oregon, Washington, and northern California. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-76, 6 pp., illus. 1968.*

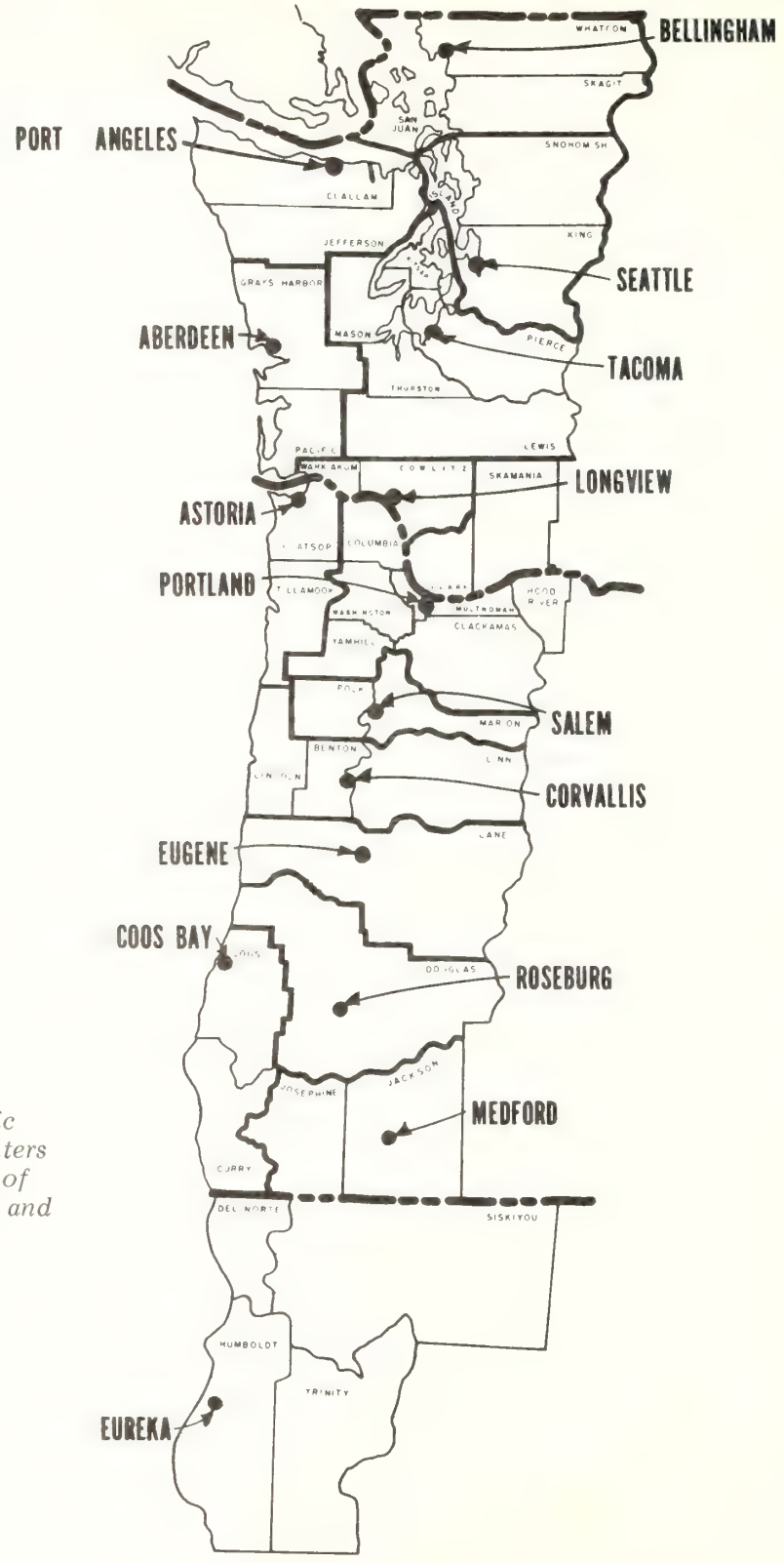


Figure 1. — Economic areas and growth centers in Douglas-fir region of Washington, Oregon, and California.

ply Study"[5] and were used in determining the dependency of the region on the forest products industry.

In each economic area, the largest city is identified as the growth center since it is usually the most rapidly growing part of the area. Each growth center and the communities in its labor and commuting area represent an economic area characterized by a high degree of economic interdependence.

Importance of Timber to Economic Areas

In order to assess the importance of log flows within the region and to point out the relative value of the timber industry and the changing log supply sources to each of the economic areas, each area's dependency on timber was examined.

As part of the special study by Maki et al. (see footnote 4), the degree of economic dependency on timber industries was estimated for each of the region's 15 subareas. Dependency was measured in terms of the percent of economic base employment within an area accounted for by timber-oriented industries. An area's economic base employment is the employment producing goods and services for markets outside the area. In contrast, service or residentiary employment produces for local consumption. Usually, most manufacturing employment falls into the economic base classification, but employment in local service industries, e.g., barbershops, shoe repair shops, drugstores, is geared to local needs.

The excess employment technique was used to identify that portion of the employment in each area which was economic base employment. This approach accepts the national distribution of employment as a norm. For any sector of an area's economy, an industry with employment in excess of this norm is considered to be producing for markets outside the area and is thus part of that area's economic base.

Each area's *timber dependency indicator* was found by determining the percent of total excess or economic base employment accounted for by excess employment in wood products industries. Percentages for the 15 economic areas fell into three distinct groups. Ten areas were rated as highly timber dependent, four areas moderately dependent, and one area, Seattle, was classed as slightly dependent.[6]

Dependency and economic area[1]	Percentage of 1960 excess employment dependent on timber-based employment
Slight:	
Seattle	6.2
Moderate:	
Portland	23.8
Salem	29.3
Bellingham	30.4
Tacoma	32.5
High:	
Astoria	63.1
Medford	70.0
Corvallis	74.3
Eugene	76.6
Longview	81.5
Aberdeen	88.1
Eureka	89.6
Port Angeles	90.5
Coos Bay	91.6
Roseburg	99.4
Douglas-fir region	44.8

[1] *Economic areas are identified by the names of their respective growth centers.*

Forest-based activities are not the sole economic support of communities in the region, but for many communities the lumber and wood products and paper and allied products industries are the primary means of support-

[5] *USDA Forest Service. Douglas-fir supply study. Regions 5 and 6 and the Pacific Northwest Forest & Range Exp. Sta. 53 pp., illus. 1969.*

[6] *In the previously mentioned study by Maki et al., the Eureka economic area consisted of Del Norte, Humboldt, and Siskiyou Counties. Trinity County has been added here, and it has been assumed the area's timber dependency would not significantly change.*

ing the local population.[7] For the region as a whole, approximately 45 percent of the economic base employment is in timber-dependent industries. However, the total importance of the forest industries does not end with the manufacture of wood-based products. Firms engaged in transportation, heavy manufacturing, and provision of other services as a result of forest industry activity also contribute to dollar flows, employment, and economic growth in the region.

The data obtained in this study have been presented in a context of functional economic areas — areas for which the timber dependency indicator has been determined. The data will allow evaluation of log flows in light of each area's dependency on timber. Relating the log flows in these people-oriented units to each unit's degree of dependency on timber-based employment may shed some light on the emerging local and regional problems associated with shifting timber-dependent economic activity and changing available timber supplies.

The importance of timber in an area's economic base provides a critical link in explaining the impacts of alternative forest resource management practices on an area. Each area's comparative advantage in the region and in national markets, as shown by the area's economic base, is a determinant of the area's prosperity and economic well-being. Armed with the knowledge of each area's dependency on the forest industries, each resource manager can judge how his management policies contribute to an area's competitive position in regional, national, and international markets.

Although counties have little relationship to the dynamic forces which influence regional economic activity, they do offer the most flexible unit of data presentation. For this reason, all data in appendix tables 13-27 are tabulated and presented by counties.

[7] *The lumber and wood products industry includes logging, lumber, plywood, poles, piling, and miscellaneous wood products (excludes furniture). The paper and allied products industry includes pulp, paper, paperboard, and building board products.*

Economic Setting in 1966

The condition of the industry at the time of the study must be known in order to place the results in the proper perspective. In the first part of 1966, the lumber and plywood industries had a high rate of production, continuing from 1965, and the outlook for the remaining part of the year was good. Orders were generally heavy, and prices were moving upward. However, by mid-April, lumber and plywood markets began to weaken, orders had started to decline, and prices were beginning to fluctuate. In May, plywood production began a sharp decline; and though lumber's decline was more gradual, when housing starts hit a 20-year low in October, gloom settled over the wood products industry. Some mills shut down temporarily, and a few closed permanently. The number of mills and their reported log consumption for 1966 may reflect the economic setting. Plants idled by the prevailing economic conditions at that time are not included in the report.

Collection of Data

Information on domestic consumption of logs by type of user from each landownership class was obtained through an industrywide canvass. A questionnaire was sent to each timber-using plant in the 38 western counties of Oregon and Washington and the four northwestern counties of California. Each plant was asked to report mill capacity, volume of logs used, and source of logs by landownership class and county of origin for the year 1966. Nonrespondents were contacted by telephone, and the requested information was obtained at that time or through a second questionnaire.

In this study, a plant is taken as the basic unit. Some firms may consist of many plants, in which case all the firm's plants within the region were contacted. Data from the following sources were used in compiling the list of plant locations: "Directory of the Forest

Products Industry," "Lockwood's Directory,"[8] the California Department of Employment, Western Wood Products Association, and the Employment Security Department of the State of Washington.

Industry Coverage

In this study, forest industry firms in the Douglas-fir region operating in 1966 were contacted: 397 sawmills, 59 veneer plants, 99 integrated veneer and plywood plants (producing both veneer and plywood), 32 plywood layup plants, 39 pulp plants, and 49 shake and shingle mills. These firms represented a complete inventory of all active firms except as noted below. (The region's pole and piling firms were not included in the study.)

Sawmills

There were 15 sawmills not using roundwood and therefore not included in the study. These mills, operating mainly on peeler cores, had a total capacity of 743,000 board feet per 8-hour shift. Most of these mills were located in Oregon.

Although an attempt was made to contact all the region's sawmills, 169 of the listed mills did not respond or could not be found. Information available from other sources for 83 of these 169 nonreporting mills showed a total listed daily capacity of 2,828,000 board feet, or about 34,000 board feet per day per mill. The nonreporting mills were distributed as follows.

Mill location	Total number	Data available from other source	
		Number	Capacity[1]
California	14	9	624
Oregon	73	37	1,324
Washington	82	37	880
Total	169	83	2,828

[1] *Thousand board feet per 8-hour day.*

Most of these nonreporting sawmills were assumed to be in the class, under 40,000 board feet per 8-hour shift. The low amount of investment needed to start a small sawmill which could bid on public timber sales or purchase logs on the open market meant the number of these small mills producing at any one time depended on the current lumber markets. In view of the conditions existing in the region's wood economy in 1966, many of these mills may have been inoperative at that time.

Plywood plants

There were three known integrated veneer and plywood operations (plants producing both veneer and plywood) not covered by this study. These had a total capacity of 349 million square feet, 3/8-inch basis, annually. Two of these plants operated only intermittently during 1966.

Shake and shingle plants

All listed shake and shingle operations were mailed a questionnaire, but due to the large number of these operations, only a few of the nonrespondents were contacted by telephone. Many of the shake and shingle operations tend to be very small and are inconsequential so far as volume of roundwood and mill capacity goes. The total number of listed shake and shingle operations, the number responding, and their capacities are shown for western Washington by county in appendix table 15.

[8] *Miller Freeman Publications. Directory of the forest products industry. Portland, Oreg., p. 563, 1967, and Lockwood Trade Journal Co., Inc. Lockwood's directory of the paper and allied trades. New York, p. 1683, 1966.*

DISTRIBUTION AND CAPACITY OF THE FOREST INDUSTRY

The region's forest industry has developed in a geographically uneven pattern. The larger sawmills and veneer and plywood plants are concentrated either near areas where old growth is available, as in the case of newer mills, or, for many of the older mills, near the population centers which used to have nearby old growth. Small sawmills are widely dispersed throughout the region. Pulp plants are located where raw material and water are most accessible, and the shake and shingle industry is found along the Washington coast because of the available cedar. In the Douglas-fir region, the lumber industry is still the largest of the three primary forest products industries, i.e., lumber, plywood, and pulp. The number of lumber producing plants far exceeds the number of plywood and pulp plants (table 1), and the volume of logs used by the lumber industry measures over half (58.0 percent) of all logs consumed in the region.

Sawmill Operations

Sawmill capacity totals 30.7 million board feet per 8-hour shift

Sawmills in the Douglas-fir region reported total capacity per 8-hour shift to be 30.7 million board feet (table 2). The Eureka economic area, which is the center of the large redwood lumber industry, had the greatest number of plants, 61, and the largest capacity, 6,565,000 board feet per shift, or 21.4 percent of total regional sawmill capacity (fig. 2). The Portland area was second with 56 saw-

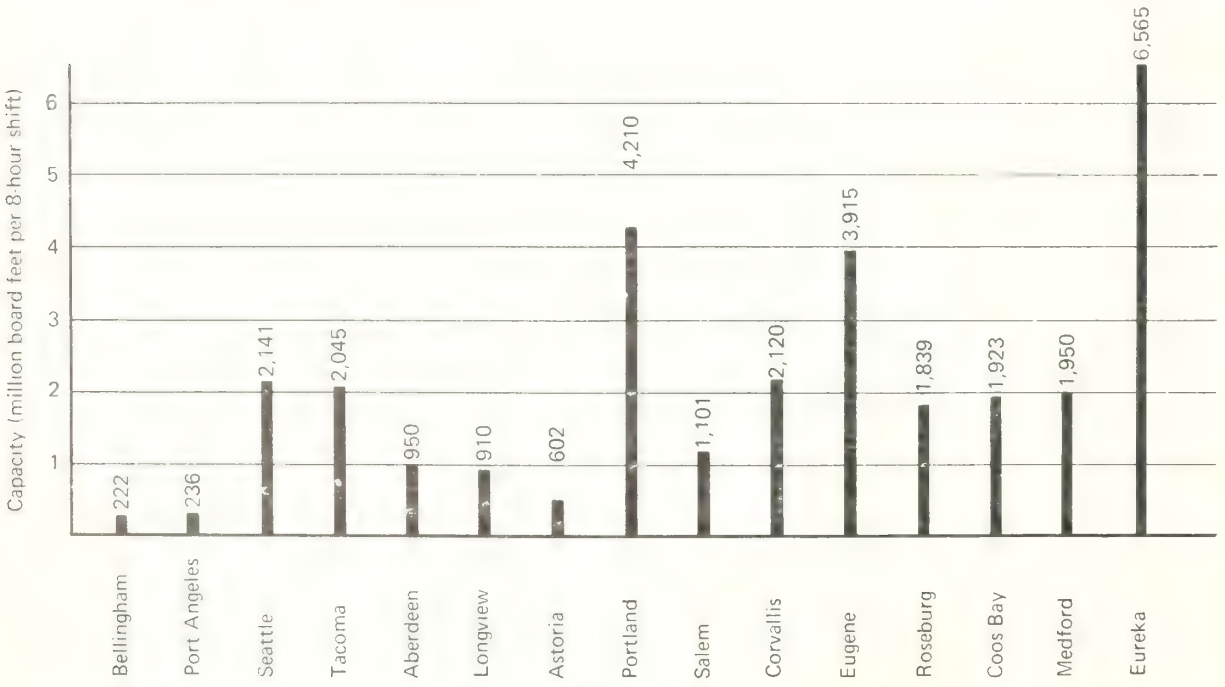


Figure 2. — Total sawmill capacity by economic area, Douglas-fir region, 1966.

Table 1. — Number of active wood product plants by type of plant and economic area, Douglas-fir region, 1966[1]

Economic areas by district	Shake and shingle	Sawmills[2]					Veneer	Veneer and plywood[3]	Plywood	Pulp	Total
		D	C	B	A	Total					
Puget Sound:											
Bellingham	8	9	2	--	--	11	--	2	--	2	23
Port Angeles	7	11	--	--	1	12	1	1	--	4	25
Seattle	3	27	4	4	4	39	1	4	1	3	51
Tacoma	7	25	10	4	4	43	6	6	5	4	71
District total	25	72	16	8	9	105	8	13	6	13	170
Columbia River:											
Aberdeen	15	3	2	1	4	10	--	6	1	2	34
Longview	4	5	2	1	2	10	--	2	--	3	19
Astoria	1	6	1	3	1	11	--	3	--	--	15
Portland	2	18	17	10	11	56	7	9	3	10	87
Salem	--	3	4	7	1	15	2	5	1	1	24
Corvallis	--	8	9	5	6	28	6	8	6	4	52
Eugene	1	5	15	11	10	41	13	18	5	1	79
District total	23	48	50	38	35	171	28	51	16	21	310
Southwest Oregon:											
Roseburg	--	5	7	10	3	25	9	7	2	1	44
Coos Bay	--	3	3	5	5	16	4	12	--	2	34
Medford	--	3	2	9	5	19	2	6	8	--	35
District total	--	11	12	24	13	60	15	25	10	3	113
Northwest California:											
Eureka	1	1	17	26	17	61	8	10	--	2	82
Total, Douglas-fir region	49	132	95	96	74	397	59	99	32	39	675

[1] *Includes only those plants that responded to the 1966 forest industry survey.*

[2] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

[3] *Integrated operations producing both veneer and plywood.*

Table 2. — Forest industry plant capacities by type of plant and economic area, Douglas-fir region, 1966[1]

Economic areas by district	Shake and shingle	Sawmills[2]					Veneer, 1/8-inch	Veneer and plywood, 3/8-inch[3]	Plywood, 3/8-inch	Pulp
		D	C	B	A	Total				
	Thousand bd. ft. per 8-hour shift						*Thousand sq. ft. per 8-hour shift*			*Tons per 24 hours*
Puget Sound:										
Bellingham	46	117	105	--	--	222	--	275	--	640
Port Angeles	125	111	--	--	125	236	100	200	--	1,552
Seattle	30	386	255	380	1,120	2,141	57	510	60	1,435
Tacoma	57	304	585	406	750	2,045	763	749	500	1,470
District total	258	918	945	786	1,995	4,644	920	1,734	560	5,097
Columbia River:										
Aberdeen	297	70	110	90	680	950	--	434	150	885
Longview	31	125	110	100	575	910	--	386	--	3,111
Astoria	9	89	50	303	160	602	--	585	--	--
Portland	12	350	1,141	935	1,784	4,210	593	2,230	101	3,436
Salem	--	46	249	661	145	1,101	155	812	272	230
Corvallis	--	178	512	470	960	2,120	863	1,071	2,238	1,549
Eugene	15	130	840	1,005	1,940	3,915	1,712	3,381	872	1,150
District total	364	988	3,012	3,564	6,244	13,808	3,323	8,899	3,633	10,361
Southwest Oregon:										
Roseburg	--	110	413	921	395	1,839	1,370	1,254	275	500
Coos Bay	--	29	155	505	1,234	1,923	850	2,593	--	325
Medford	--	65	115	895	875	1,950	700	1,891	1,962	--
District total	--	204	683	2,321	2,504	5,712	2,920	5,738	2,237	825
Northwest California:										
Eureka	11	10	1,127	2,418	3,010	6,565	1,111	1,797	--	1,000
Total, Douglas-fir region	633	2,120	5,767	9,089	13,753	30,729	8,274	18,168	6,430	17,283

[1] *Includes only those plants that responded to the 1966 forest industry survey.*

[2] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

[3] *Integrated operations producing both veneer and plywood.*

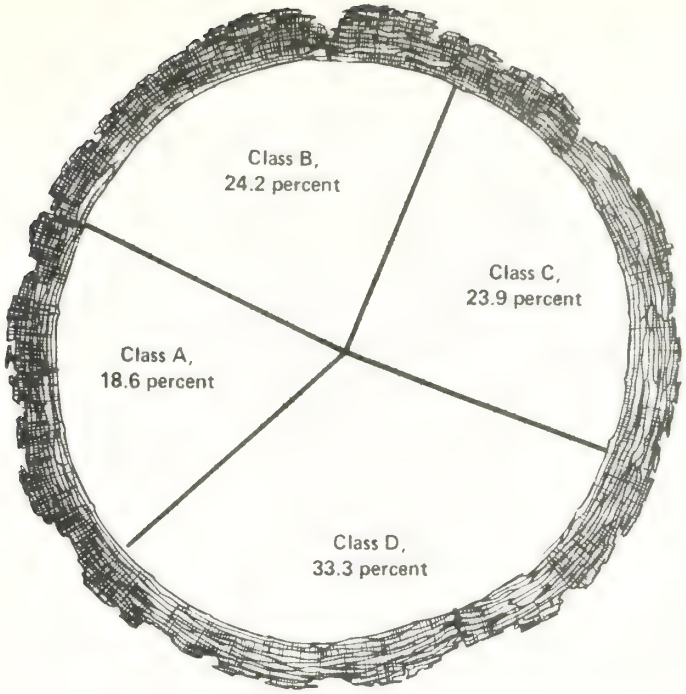


Figure 3. —Percent of Douglas-fir region sawmills in each mill size class, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

mills and a capacity of 4,210,000 board feet per shift. Bellingham had the smallest lumber industry with only 11 sawmills and a capacity of 222,000 board feet per shift.

Technological advancements and a continually changing market have made it possible for sawmills to operate without relying on the large, old-growth Douglas-fir which was once the backbone of the lumber industry. Today's lumber industry varies in size from plants producing a few thousand board feet per shift to mills producing in excess of 120,000 board feet per shift.

Sawmills were grouped into four classes, according to the lumber production capacity for a single 8-hour shift, as follows:

Class	*Capacity, board feet per 8-hour shift*
A	120,000+
B	80,000-119,000
C	40,000-79,000
D	Less than 40,000

A total of 397 sawmills were contacted in the region. Of this total, 33 percent were class D plants, 24 percent class C, 24 percent class B, and 19 percent class A (fig. 3).

Class A sawmills have 44.7 percent of region's lumber producing capacity; Eureka area most important

There were 74 large sawmills (120,000 board feet or more per 8-hour shift) in the region, providing 44.7 percent of the region's total sawmill capacity (figs. 4 and 5). The largest concentration of these mills was in the Eureka area where there were 17 plants with a total capacity of 3,010,000 board feet per shift, 21.9 percent of total large sawmill capacity (fig. 6). Eureka's class A sawmill capacity was more than half again as large as the capacity of large sawmills in any other area. The Eugene economic area was second in importance, with 1,940,000 board feet per shift.

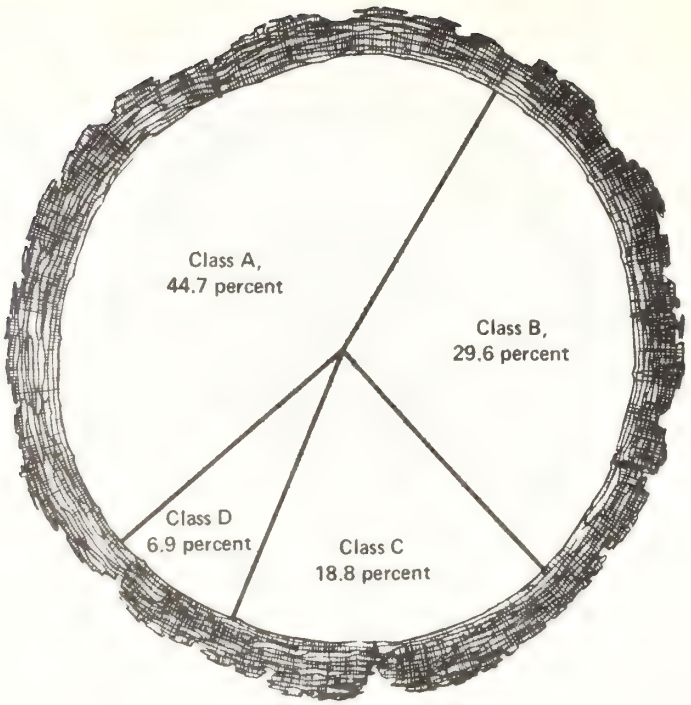


Figure 4. — Percent of Douglas-fir region sawmill capacity in each mill size class, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-179,000; D = less than 40,000.

Class B sawmills have 29.6 percent of region's sawmill capacity; also concentrated in Eureka area

Class B sawmills, 80,000-119,000 board feet capacity per 8-hour shift, totaled 96 mills in the region in 1966 and 29.6 percent of the region's total lumber manufacturing capacity. The Eureka economic area, with its concentration of redwood sawmills, had 26 class B mills with a capacity of 2,418,000 board feet per 8-hour shift (fig. 7). This was 26.6 percent of the total regional "medium large" sawmill capacity and more than double the class B capacity of any other economic area (fig. 8). The Eugene economic area was second in capacity with 1,005,000 board feet.

Class C sawmills concentrated in Portland and Eureka economic areas

Class C, mills with a capacity of 40,000-79,000 board feet per shift, was made up of 95 sawmills and represented 18.8 percent of the region's total sawmill capacity. The largest number of these mills was located in the Portland and Eureka economic areas, both with 17 plants (fig. 9). The Portland economic area had a slightly higher capacity, 1,141,000 board feet per 8-hour shift versus 1,127,000 board feet for the Eureka area (fig. 10). Portland had 19.8 percent of the region's total for this class.

Class D sawmills concentrated in Seattle economic area

There were 132 small mills in class D, representing 6.9 percent of total sawmill capacity in the region (fig. 11). These small mills were concentrated in three areas that are among the oldest major lumber producing areas in the West. The Seattle and Tacoma areas combined had 52 mills representing 32 percent of the small mill capacity, and the Portland area had 18 small mills (fig. 12).

Twenty mills which used hardwoods only have been included in the above figures. These mills were all in class D — under 40,000 board feet per 8-hour shift — and had a total capacity of 279,000 board feet per shift. Total log volume utilized by these operations

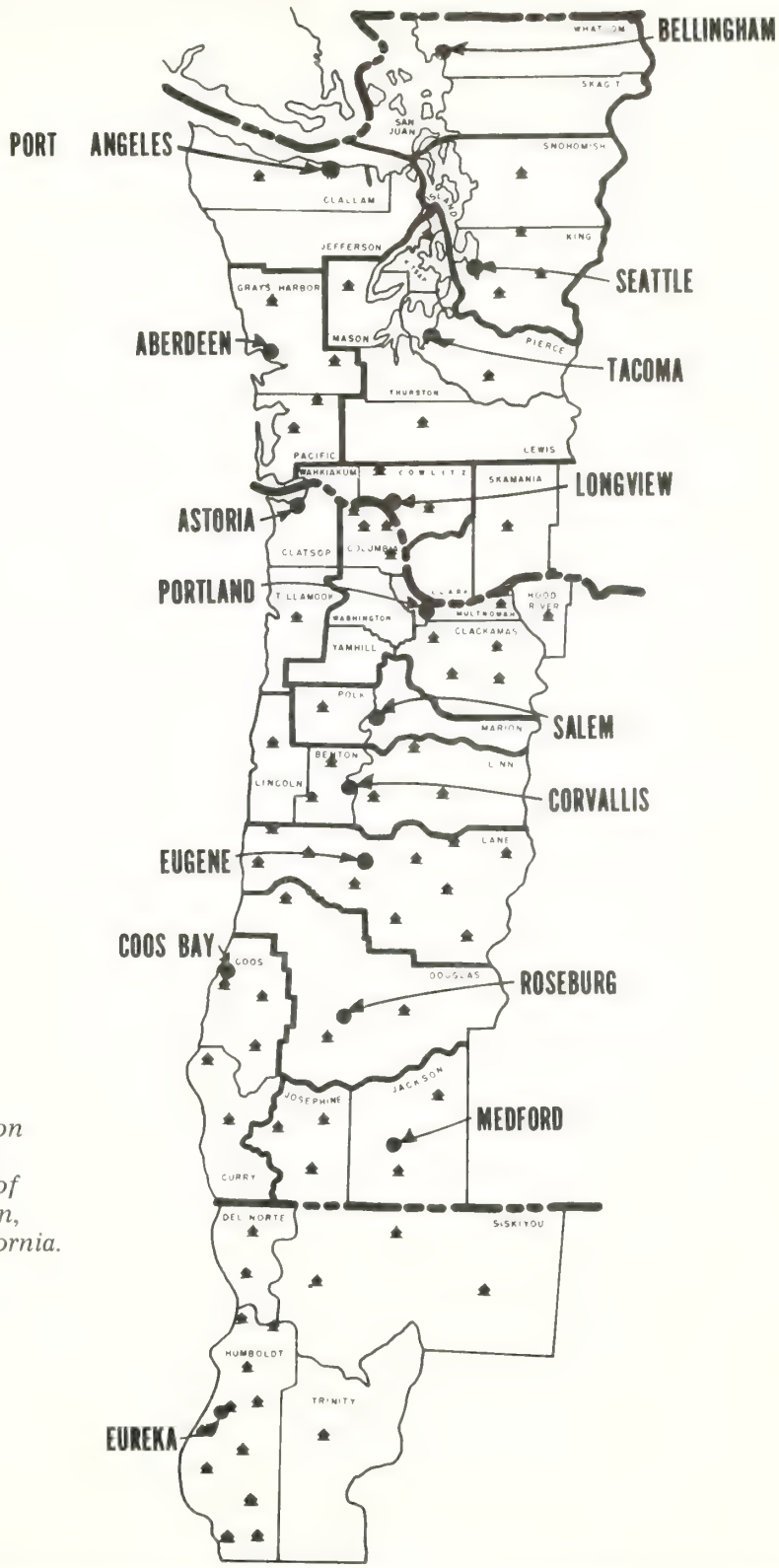


Figure 5. — Location of class A sawmills, Douglas-fir region of Washington, Oregon, and northern California.

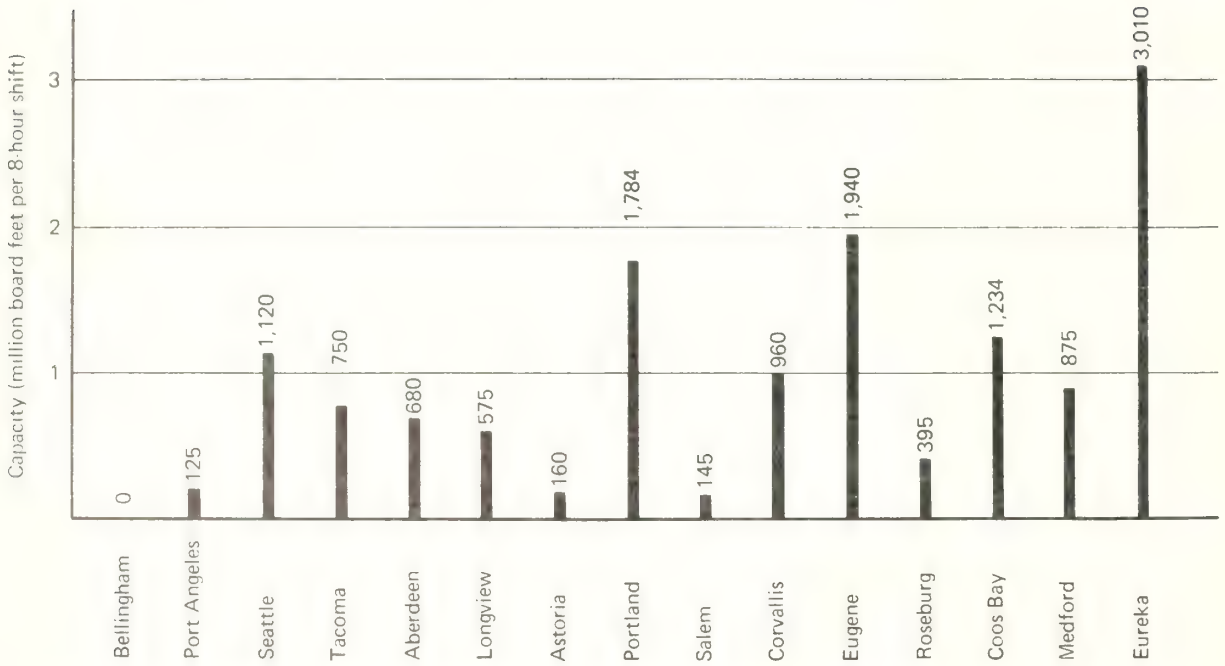


Figure 6. — Capacity of class A sawmills by economic area, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift.

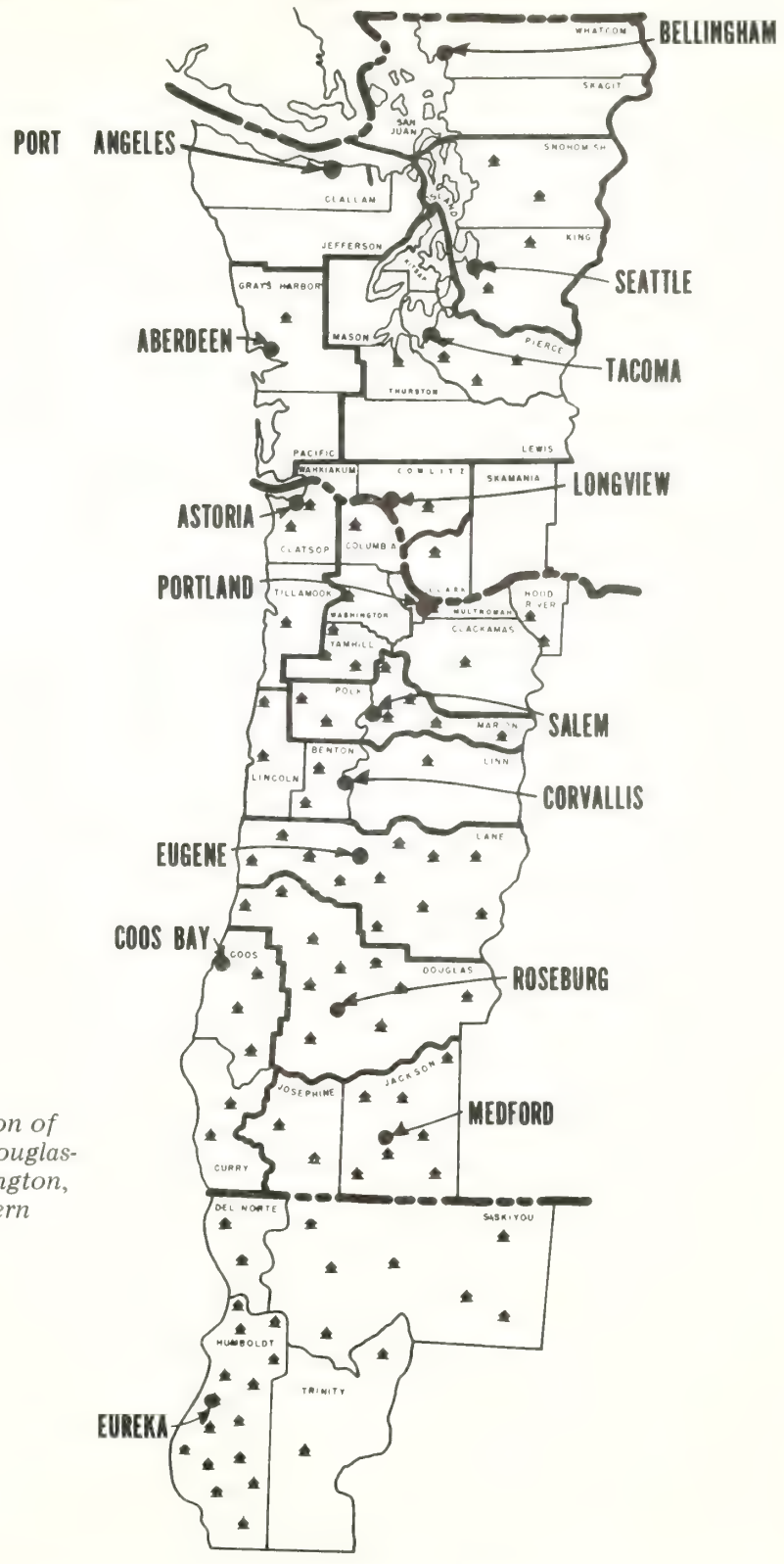


Figure 7. — Location of class B sawmills, Douglas-fir region of Washington, Oregon, and northern California.

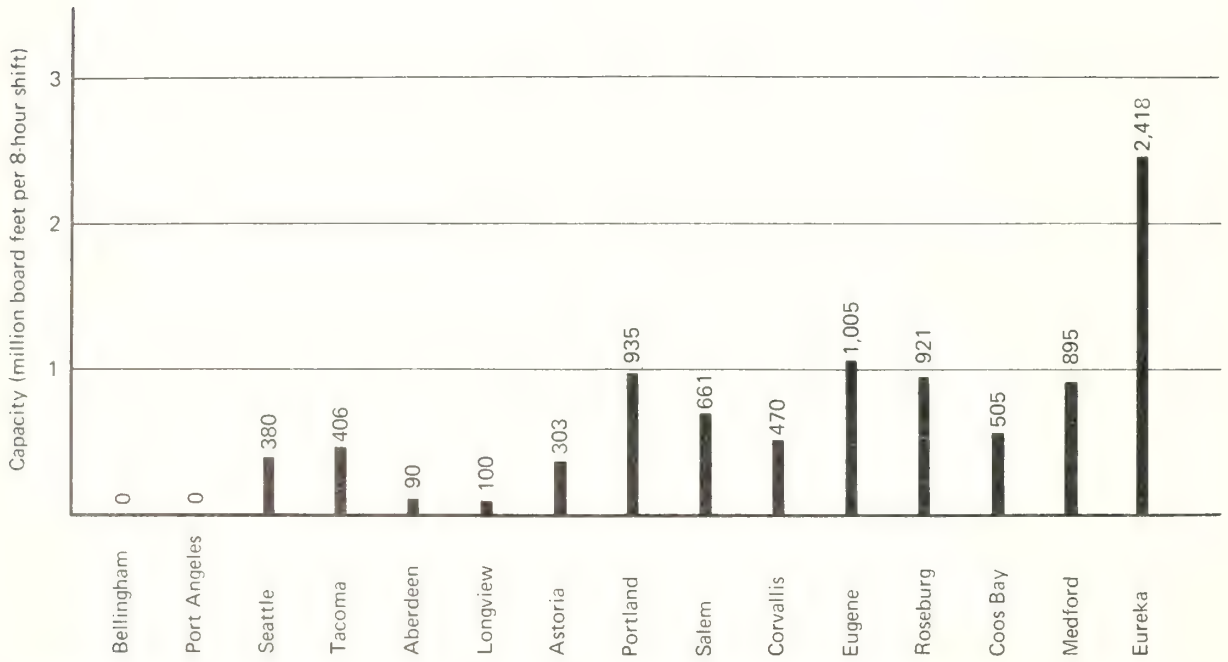


Figure 8. – Capacity of class B sawmills by economic area, Douglas-fir region, 1966. Class B sawmills = 80,000-119,000 board feet capacity per 8-hour shift.

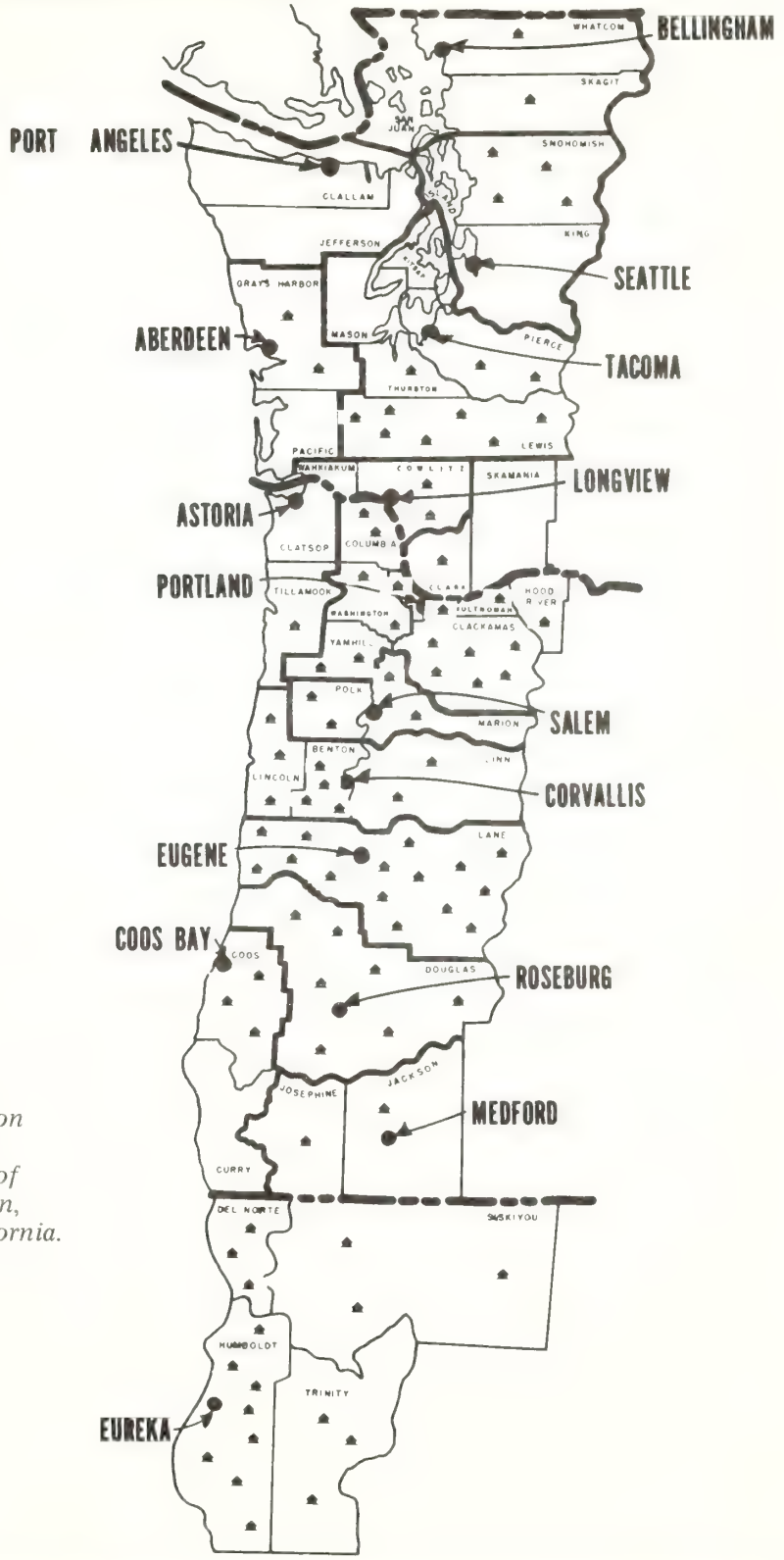


Figure 9. — Location of class C sawmills, Douglas-fir region of Washington, Oregon, and northern California.

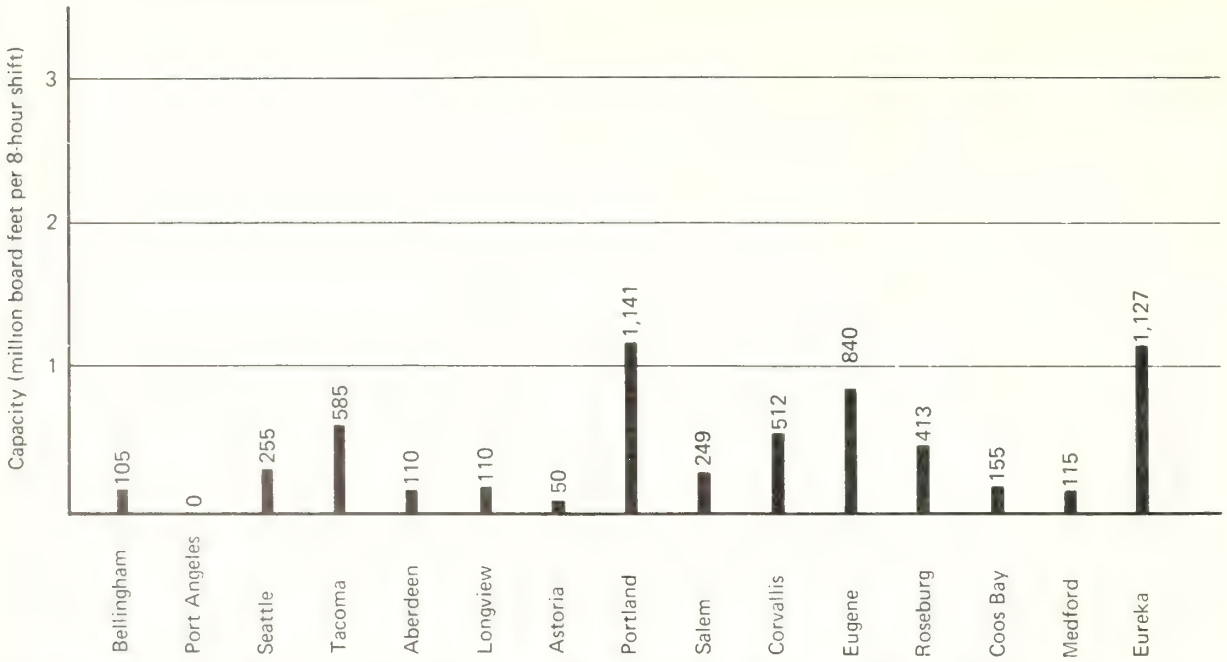


Figure 10. — Capacity of class C sawmills by economic area, Douglas-fir region, 1966. Class C sawmills = 40,000-79,000 board feet capacity per 8-hour shift.

was 54.7 million board feet, of which 51.9 million board feet was purchased from private lands. The Longview economic area in Washington had the largest hardwood mill capacity.

Lumber industry in western Washington smaller but more stable than in western Oregon

In general, the average sawmill in western Oregon is much larger than in western Washington. About two-thirds of the class D mills were located in Washington, with Oregon leading in numbers of the other three classes of mills. Another study showed that, from 1947 to 1960, lumber mills in Oregon outstripped the growth in size of similar establishments in Washington and California.[9] This same study pointed out that the mortality rate has grown steadily higher and the birth rate lower for smaller companies as compared with large companies in the region, and, in general, lumber companies had declined in number but grown in size. Although the data in this study were based on entire companies rather than on individual plants, they are useful in examining trends in number of plants because the number and size of plants bear a high correlation to the number and size of companies.

Data shown in table 3 compare the lumber industry in western Washington with that in western Oregon. The trend from 1950 to 1966 indicates a more stable situation in Washington and an increase in the size of sawmills in Oregon.

Plywood Industry

Plywood industry 1966 annual capacity 24.6 million square feet; concentrated in Eugene, Medford, and Corvallis areas

The plywood industry consists of three major components: veneer operations, inte-

[9] *Ho, Franklin Y. H. Small lumber companies in western Oregon. University of Portland, 119 pp., illus., 1963.*

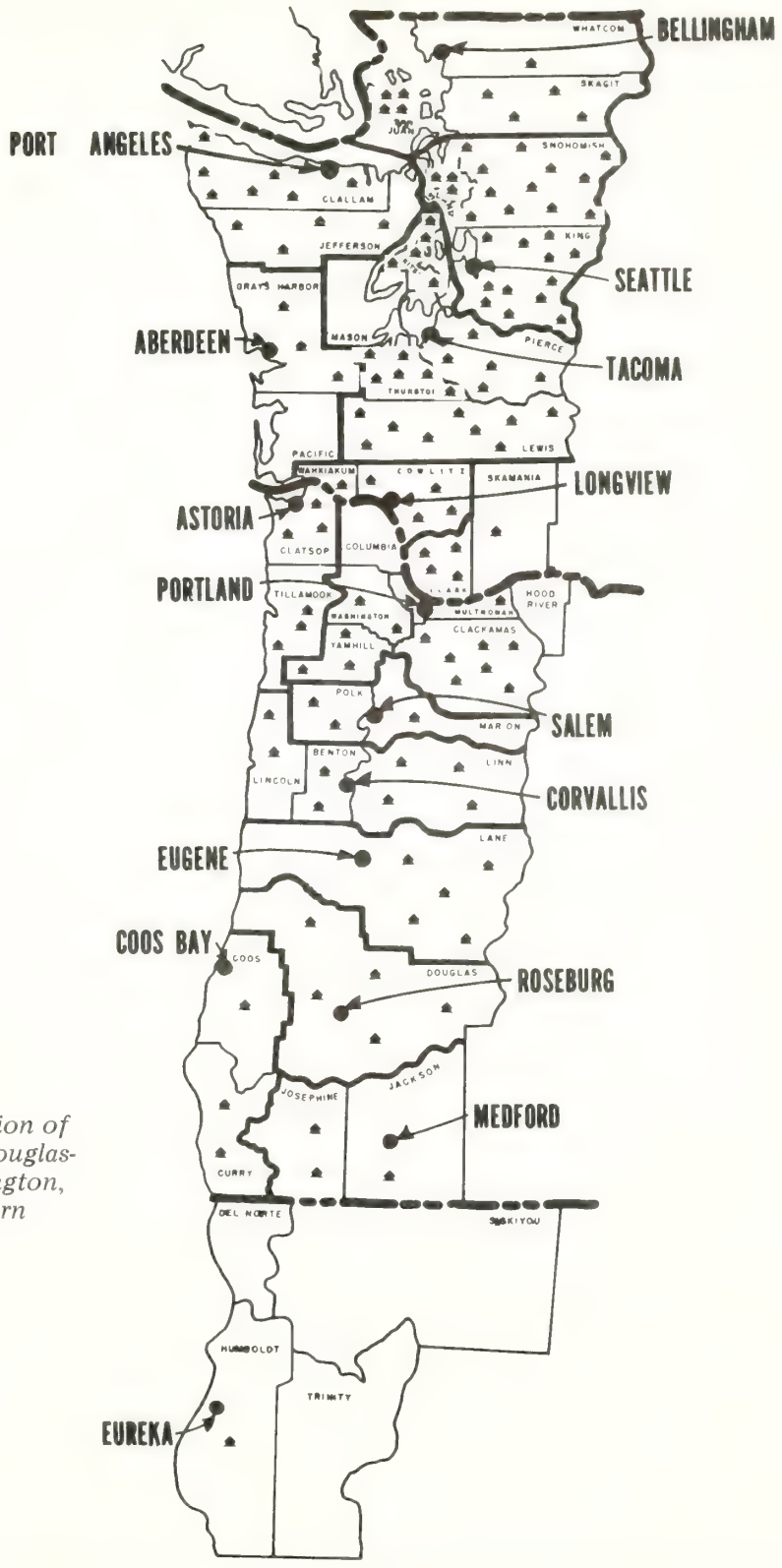


Figure 11. — Location of class D sawmills, Douglas-fir region of Washington, Oregon, and northern California.

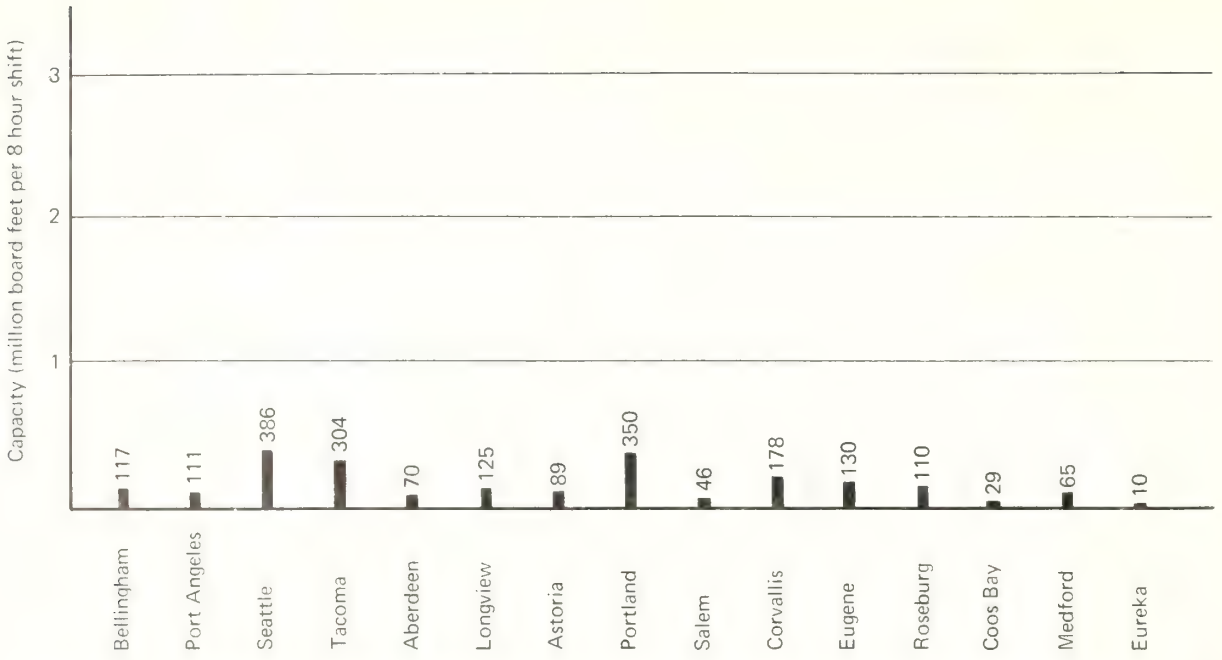


Figure 12. — Capacity of class D sawmills by economic area, Douglas-fir region, 1966. Class D sawmills = less than 40,000 board feet capacity per 8-hour shift.

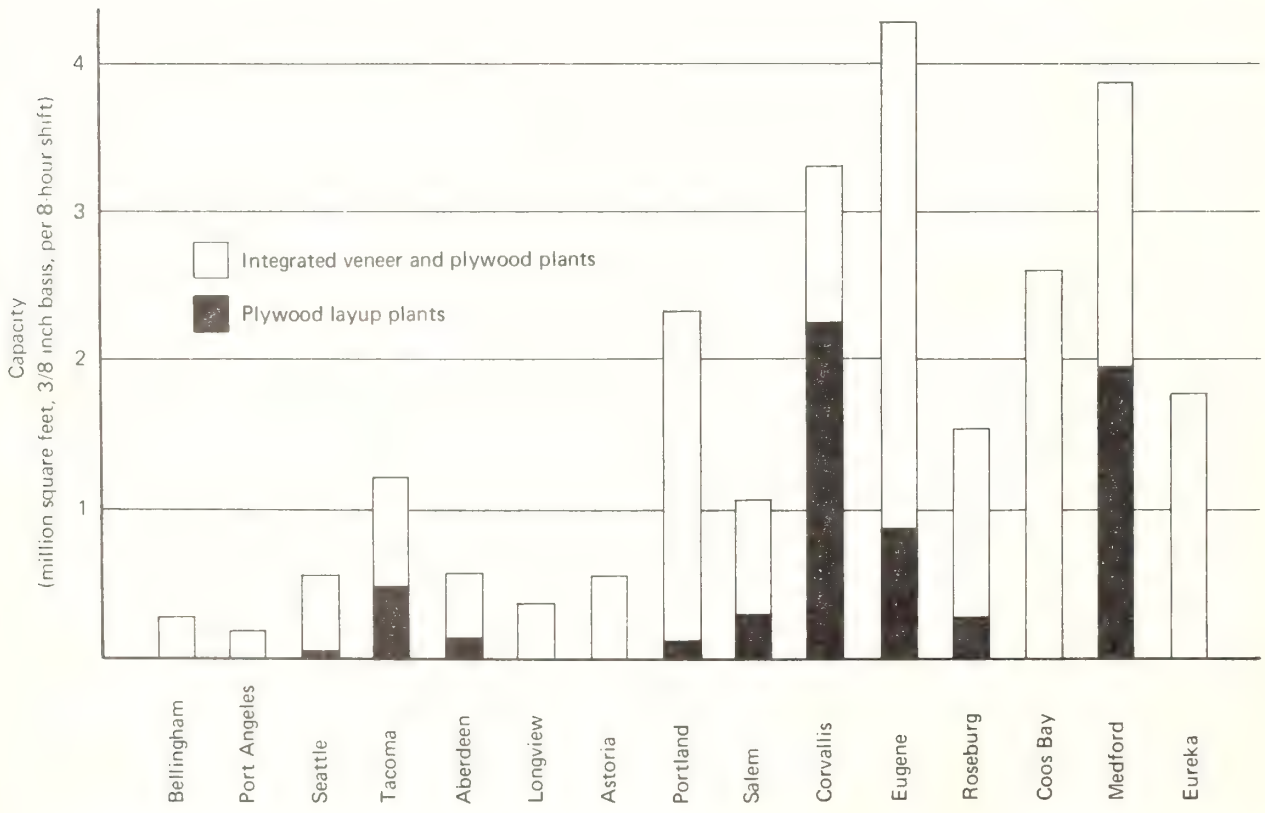


Figure 13. — Capacity of plywood producing plants by economic area, Douglas-fir region, 1966.

Table 3. – Distribution of sawmills in western Oregon and western Washington, by size class, specified years, 1950-66

(Percent)

Year	Sawmills[1]				
	D	C	B	A	Total
Western Oregon:					
1950	67	19	6	8	100
1960	39	28	19	14	100
1966	23	28	29	20	100
Western Washington:					
1950	69	12	6	13	100
1960	62	20	6	12	100
1966	64	16	8	12	100

Source: Data for 1950 and 1960 from Ho, Franklin Y. H. Small lumber companies in western Oregon. Table II-6. University of Portland, 1963.

[1] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

grated veneer and plywood operations which produce both veneer and finished plywood, and plywood layup plants which operate on purchased veneer.

Combining capacities of integrated veneer and plywood operations with plywood layup plants gave the region a total 1966 plywood capacity of 24,598,000 square feet, 3/8-inch basis, per 8-hour shift. Over 46 percent of the capacity was in the areas of Eugene, Medford, and Corvallis (table 4 and fig. 13). The Eugene area alone accounted for 17.3 percent of the capacity. In general, the lowest plywood capacity was found in those areas on the west coast of Washington and northwestern Oregon.

Until the latter part of the 1940's, about two-thirds of the region's plywood industry was in western Washington, with 50 percent or more in the Puget Sound area. However, when the center of log production shifted from western Washington to western Oregon in the early 1940's plywood production followed suit. By the early 1950's, the center of production had shifted to northern California and southwestern Oregon, where the availability of large, old-growth Douglas-fir logs containing a high percentage of peeler grade was the basis for expansion. As technologies changed and markets for low-grade plywood developed, the plywood industry was able to peel larger quantities of smaller saw-log grades and species other than Douglas-fir. This allowed the industry to expand beyond the old-growth concentrations in the region.

Today, in terms of value added by manufacture, the plywood industry ranks second in importance to the lumber industry in Oregon and third, behind lumber and pulp, in Washington. In 1966, the plywood industry consumed 30.8 percent of all logs used in domestic production in the region.

Table 4. — Plywood capacity in the Douglas-fir region, by economic area, 1966
(Thousand square feet, 3/8-inch basis, per 8-hour shift)

Economic areas by district	Capacity of —		
	Integrated veneer and plywood plants[1]	Plywood layup plants	Total plywood
Puget Sound:			
Bellingham	275	--	275
Port Angeles	200	--	200
Seattle	510	60	570
Tacoma	749	500	1,249
District total	1,734	560	2,294
Columbia River:			
Aberdeen	434	150	584
Longview	386	--	386
Astoria	585	--	585
Portland	2,230	101	2,331
Salem	812	272	1,084
Corvallis	1,071	2,238	3,309
Eugene	3,381	872	4,253
District total	8,899	3,633	12,532
Southwest Oregon:			
Roseburg	1,254	275	1,529
Coos Bay	2,593	--	2,593
Medford	1,891	1,962	3,853
District total	5,738	2,237	7,975
Northwest California:			
Eureka	1,797	--	1,797
Total, Douglas-fir region	18,168	6,430	24,598

[1] *Integrated operations producing both veneer and plywood.*

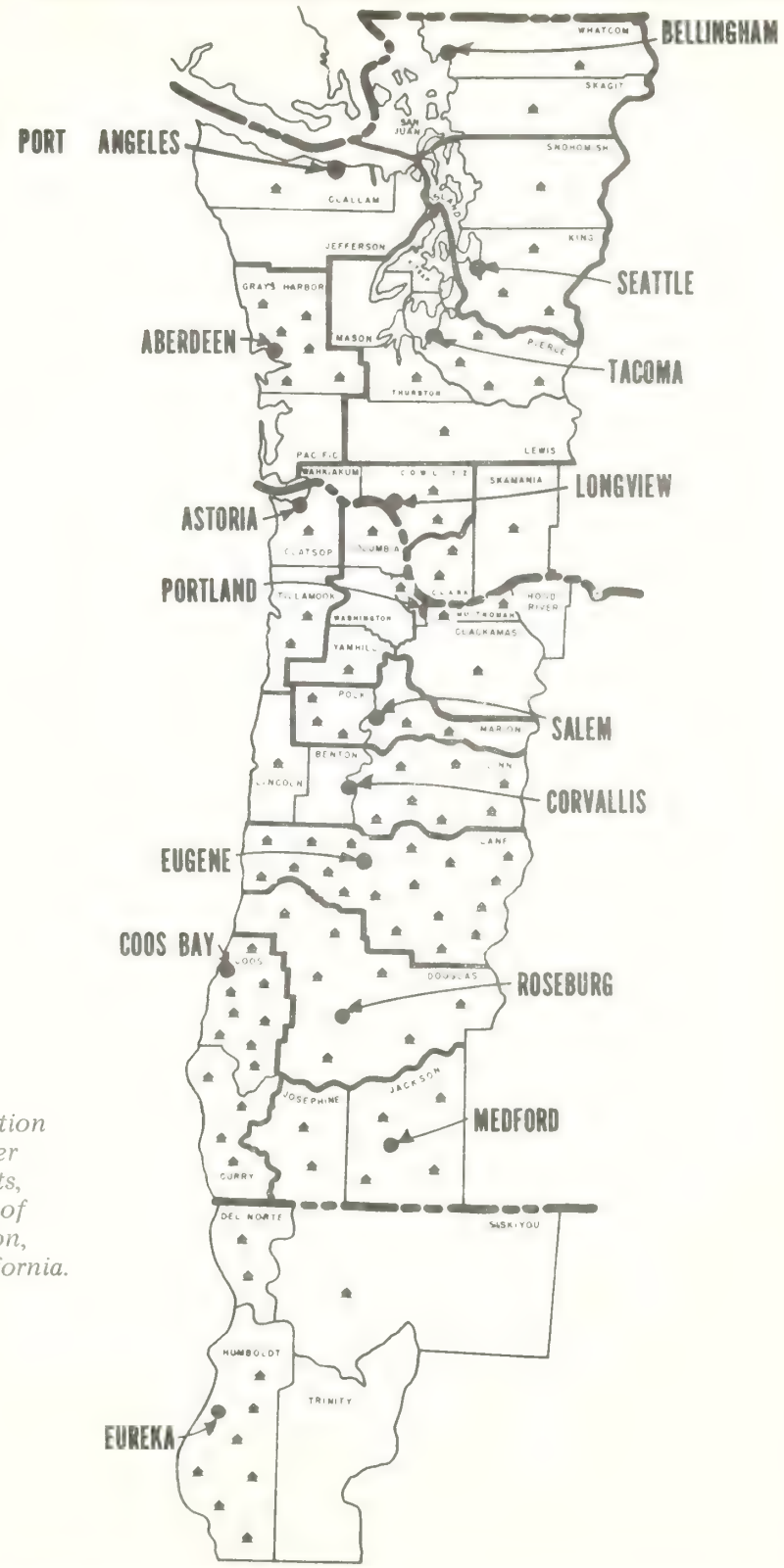


Figure 14. — Location of integrated veneer and plywood plants, Douglas-fir region of Washington, Oregon, and northern California.

Integrated veneer and plywood operations concentrated in Eugene economic area

The Eugene area had the largest number (18) of integrated veneer and plywood plants (producing both veneer and plywood) with a plant capacity of 3,381,000 square feet, 3/8-inch basis, per 8-hour shift, or 18.6 percent of the region's total capacity (fig. 14, table 4).

Douglas-fir region integrated plants accounted for 21.5 percent of the total volume of logs utilized in regional production: 29.5 percent of the logs consumed in Oregon, 13.8 percent of Washington's logs, and 10.7 percent of northern California's logs.

Integrated veneer and plywood plants operated largely on logs, with 95 percent of their input in this form. The remaining 5 percent was in the form of purchased veneer used by the plywood portion of the operation. Oregon plants relied a little more on logs (98 percent) than either Washington (89 percent) or California (85 percent).

Veneer operations concentrated in Eugene and Roseburg areas

In 1966, the Douglas-fir region had 59 veneer plants with a reported capacity of 8,274,000 square feet, 1/8-inch basis, per 8-hour shift (table 1, fig. 15). The largest concentration of veneer operations was in the Eugene economic area, with 13 plants and 20.7 percent of the region's veneer capacity. The Roseburg area, with nine plants, had 16.6 percent of the veneer capacity. Four areas, Bellingham, Aberdeen, Longview, and Astoria, had no veneer operations. Veneer operations accounted for 8.7 percent of the total logs consumed in the region.

Plywood layup capacity concentrated in Corvallis economic area

In the Douglas-fir region, there were 32 plywood layup operations having a total capacity of 6,430,000 square feet, 3/8-inch basis, per 8-hour shift (table 1, fig. 16).

The Medford economic area had eight plywood layup plants, followed by the Corvallis area with six. However, the Corvallis area plants had a plywood capacity of 2,238,000 square feet per shift versus 1,962,000 square feet for layup plants located in Medford. These layup plants relied on one or more of the veneer operations for their veneer requirements.

In general, veneer plants are located as close as possible to their timber supply to reduce log transportation costs, and layup plants are situated so as to take better advantage of the rail transportation needed to market their product.

Pulp Industry

Pulp operations concentrated near Columbia River

The pulp industry is the second oldest manufacturing industry in the region. Availability of large quantities of spruce and hemlock needed for sulfite pulp and adequate water supplies dictated the location of the first pulp plants. Since then, technological changes and expanding markets for all kinds of woodpulp-based products have allowed the industry to expand geographically and diversify production. In 1966, the pulp industry accounted for 10.9 percent of the region's total log consumption.

Western Washington and western Oregon pulp capacity increases 1.3 million tons in 6 years

The annual pulp capacity for western Oregon and western Washington, assuming 350 24-hour operating days, is 5,699,050 tons. Western Oregon's share is 2,044,000 tons yearly, and western Washington's share, 3,655,050 tons. Compared with Fedkiw's findings,[10] since 1960, western Oregon's capacity has increased by 715,000 tons and western Washington's by 622,000 tons.

The pulp industry is concentrated near the Columbia River where 21 of the region's 39 mills are located, with a capacity of 10,361 tons or 59.9 percent of the total daily capacity (table 2, fig. 17). The Portland economic area, straddling Oregon and Washing-

[10] *Fedkiw, John. Forest industry capacity, production, and available log supplies in the Douglas-fir subregion. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-11, 63 pp., illus. 1964.*

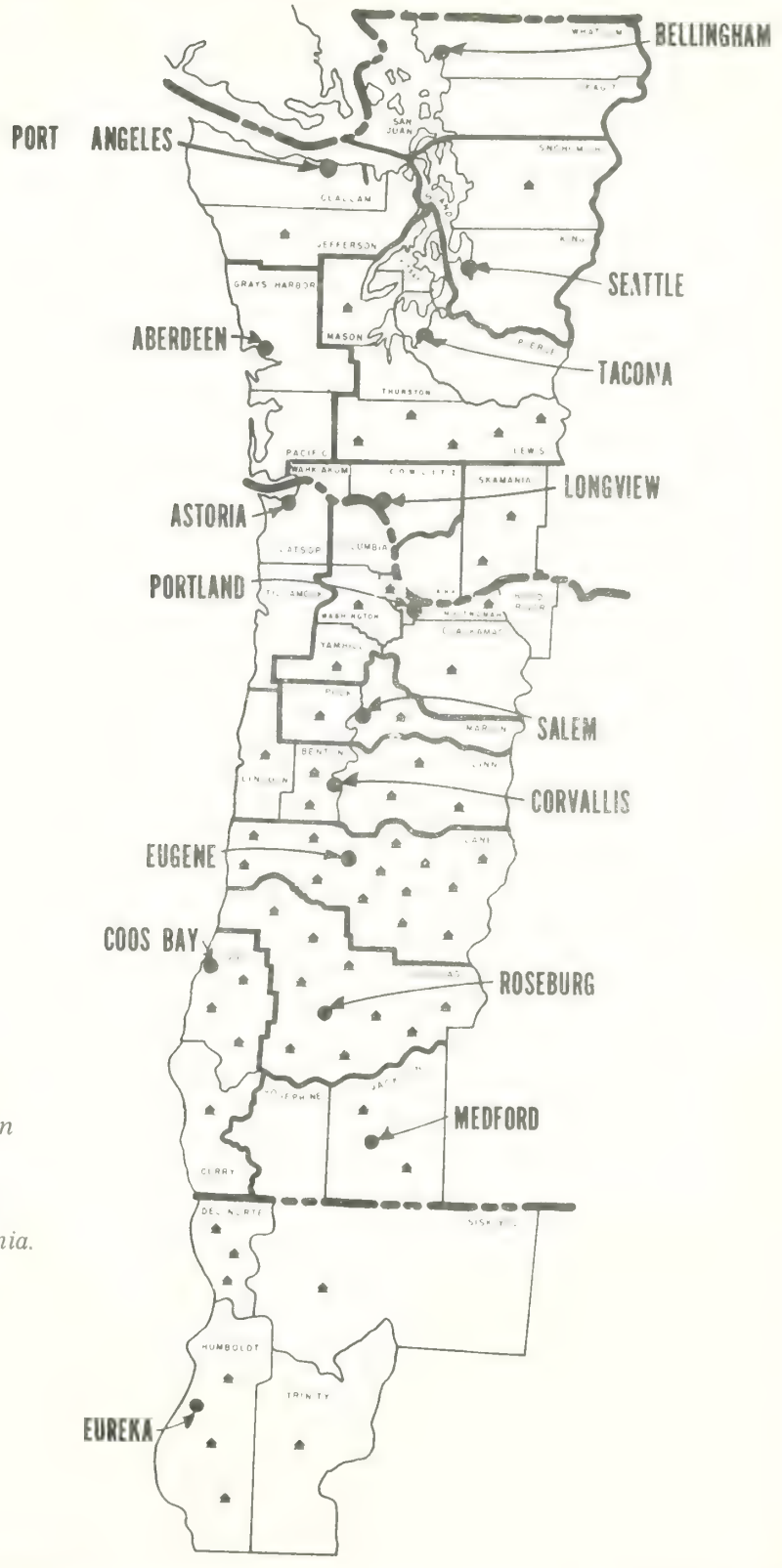


Figure 15. — Location of veneer plants, Douglas-fir region of Washington, Oregon, and northern California.

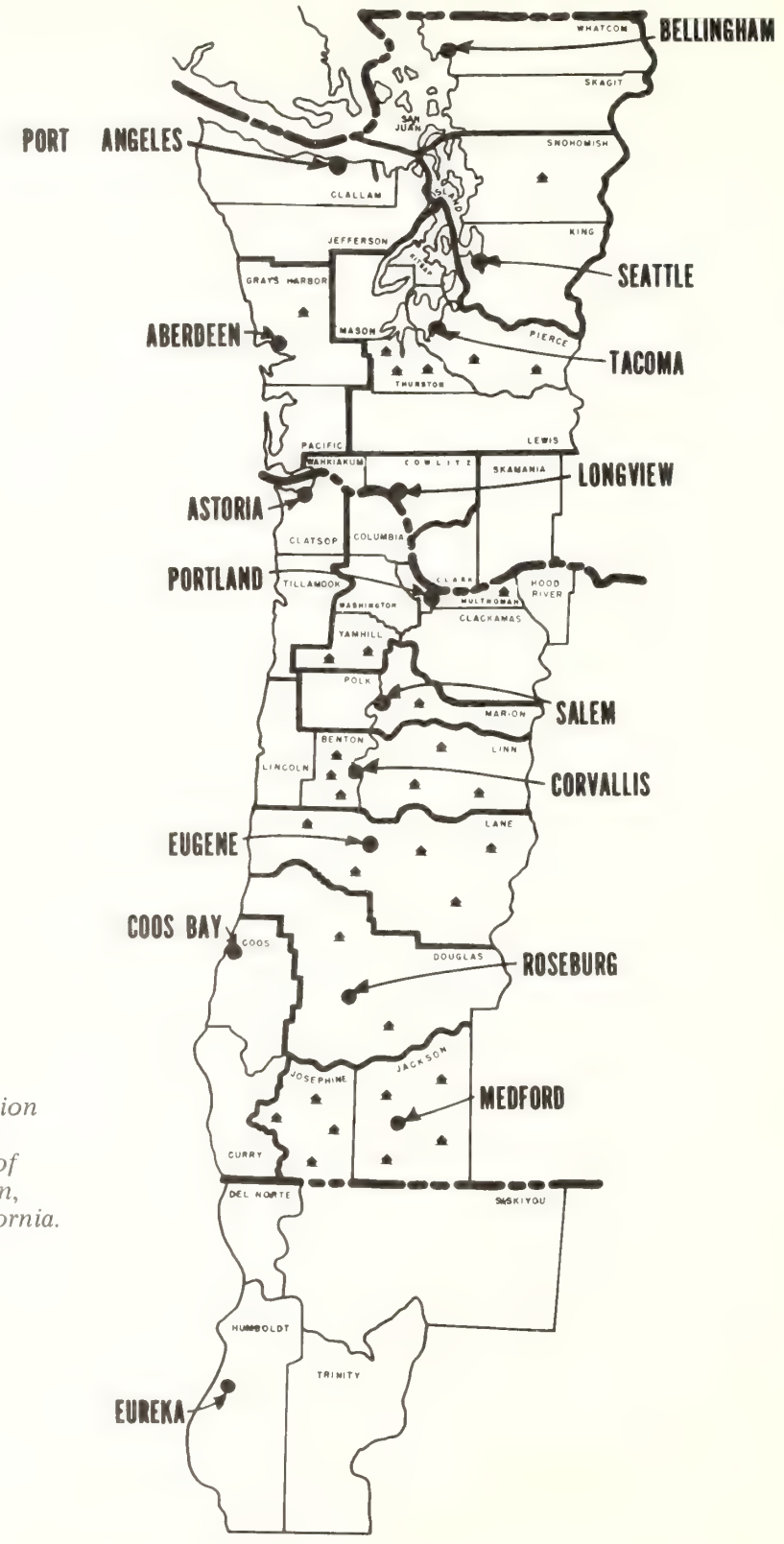


Figure 16. — Location of plywood plants, Douglas-fir region of Washington, Oregon, and northern California.

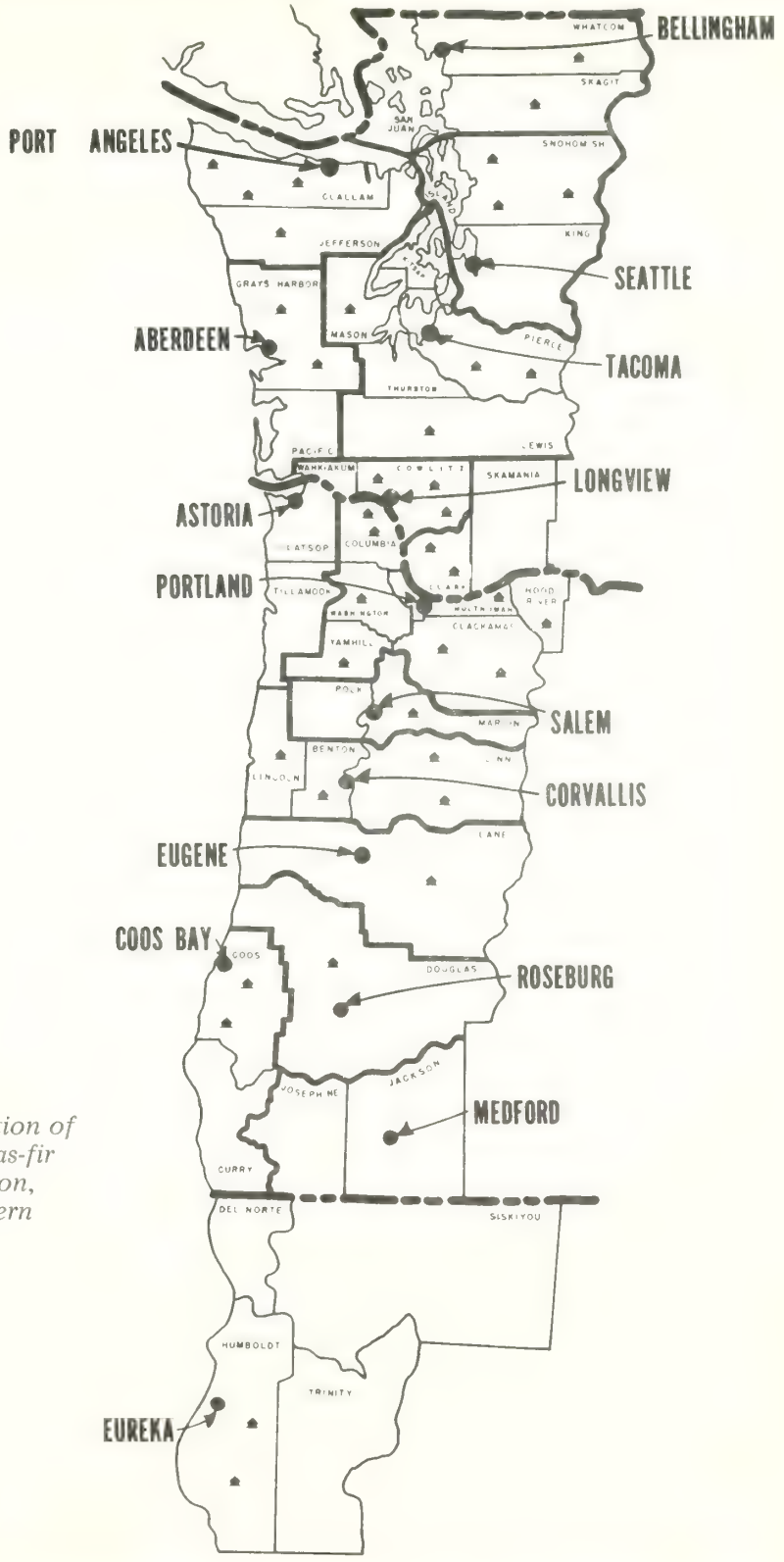


Figure 17. — Location of pulp plants, Douglas-fir region of Washington, Oregon, and northern California.

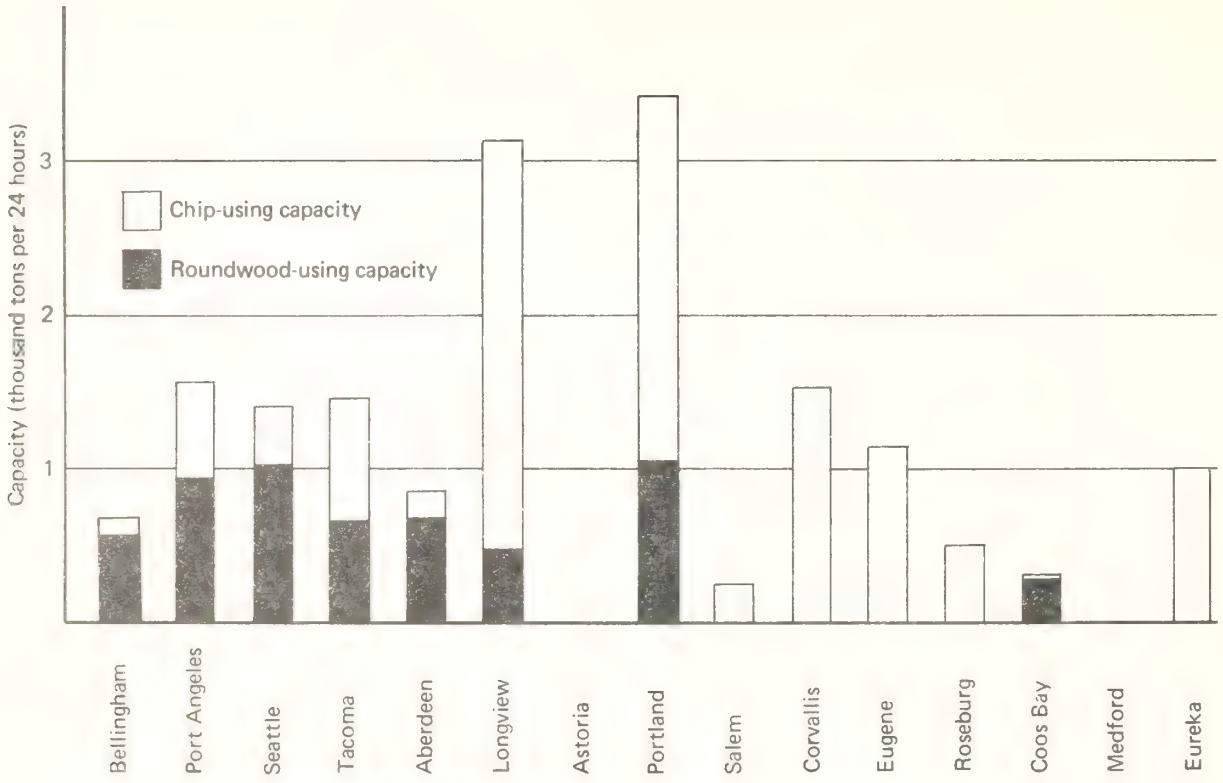


Figure 18. — Capacity of pulpmills by economic areas, Douglas-fir region, 1966.

ton on the Columbia River, had the highest pulp capacity with 3,436 tons per 24 hours (fig. 18). The Longview area, also on the river, followed with 3,111 tons.

Shake and Shingle Operations

Shake and shingle operations concentrated in western Washington

Most of the shake and shingle operations responding to the canvass were located in western Washington with the Aberdeen economic area reporting the highest shake and shingle mill capacity, 297,000 board feet per 8-hour shift (table 2, fig. 19). The Port Angeles area was second in mill capacity, and the Bellingham area was second in number of plants. All but two of the operations were in the class, under 40,000 board feet capacity per 8-hour shift. Most of these mills were geographically so located as to take advantage of the western redcedar growing in western Washington.

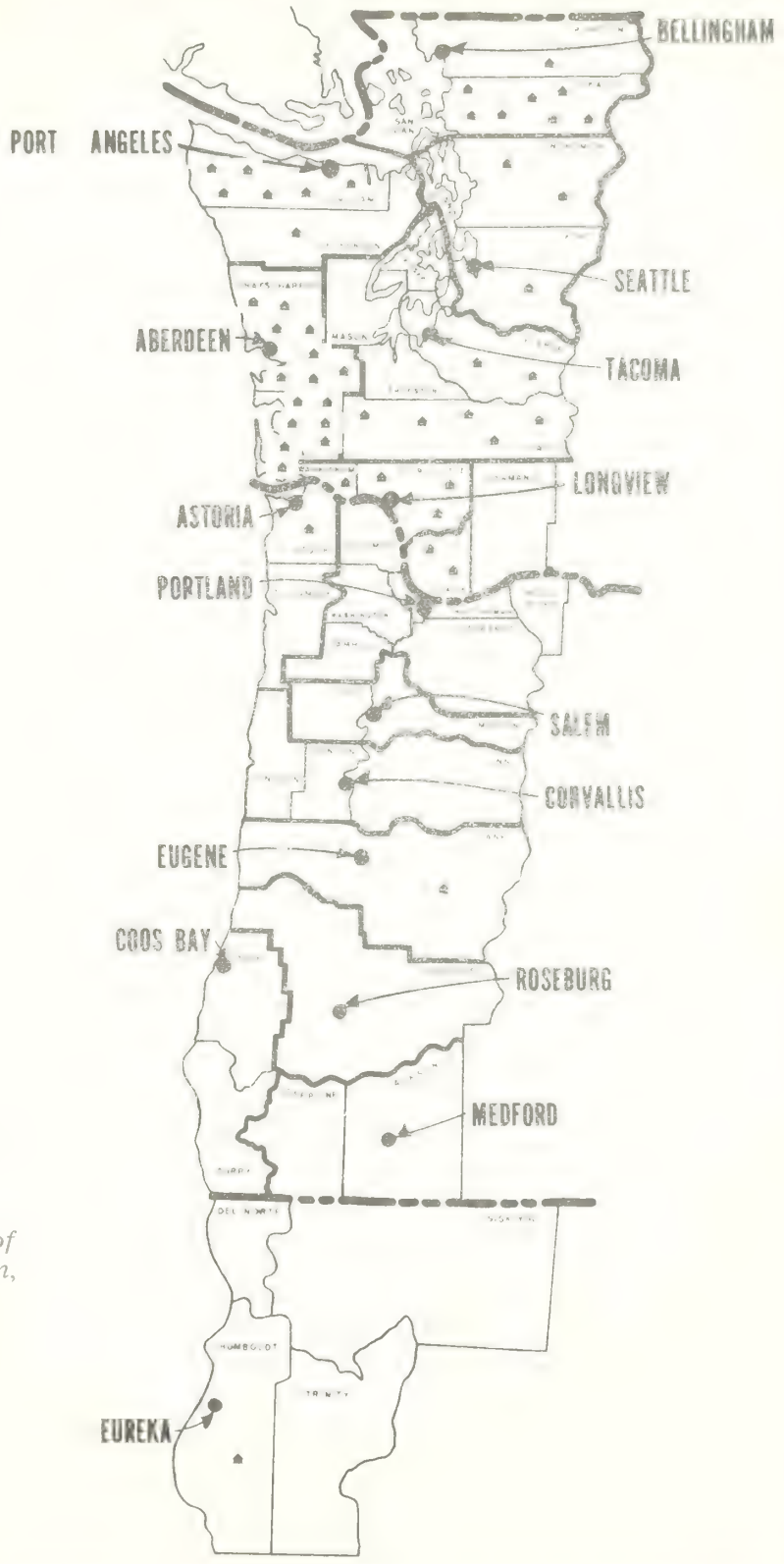


Figure 19. — Location of responding active shake and shingle mills, Douglas-fir region of Washington, Oregon, and northern California.

LOG CONSUMPTION BY ECONOMIC AREAS AND TYPE OF INDUSTRY

Eureka economic area region's largest log market; over 2 billion board feet used in 1966

The Eureka economic area was the region's largest log market in 1966, utilizing 2,120 million board feet of logs or 15.4 percent of total regional log consumption by wood products manufactured (table 5, fig. 20). This area's heavy log use is a reflection of the large redwood lumber industry in the area. As previously noted, the area has the largest sawmill capacity in the region, leading in both class A and B sawmills and second only to the Portland area in capacity of class C sawmills.

Four other areas in the region consumed over 1 billion board feet of logs each in

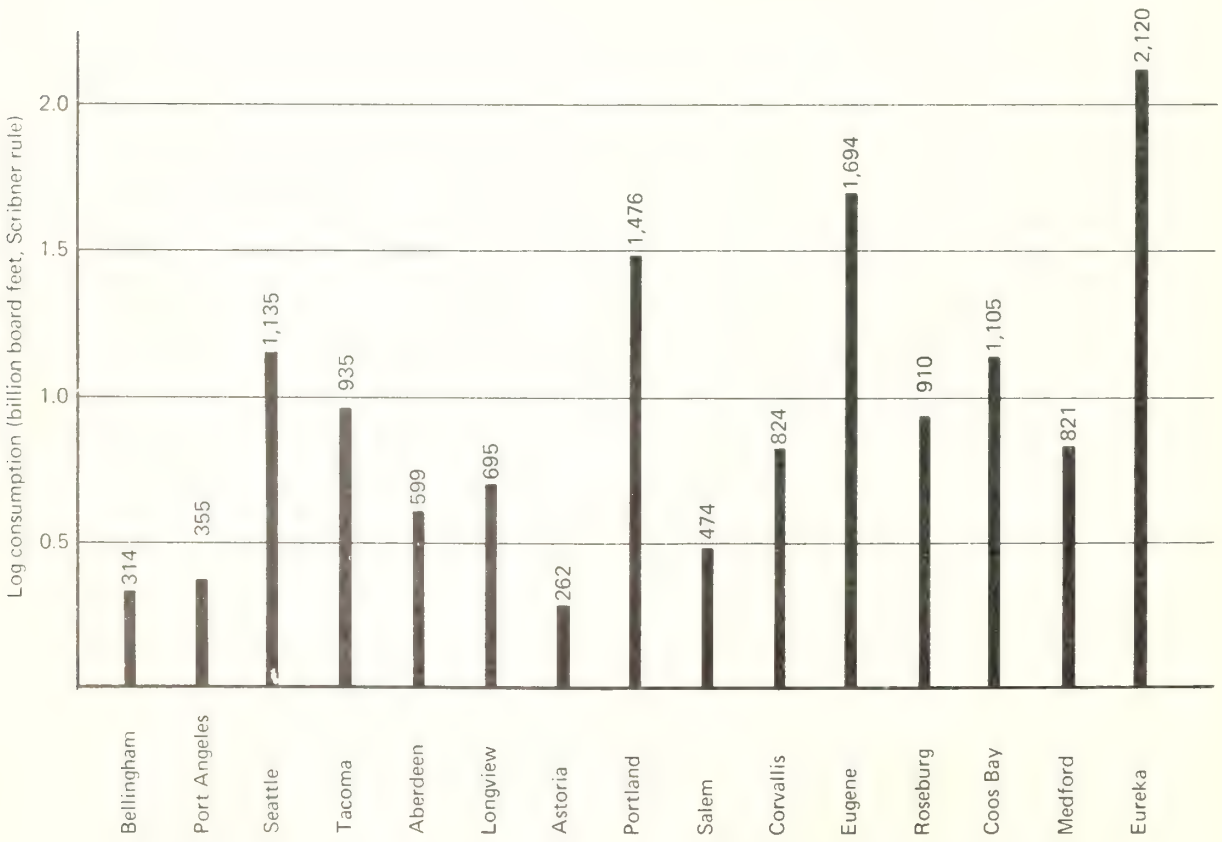


Figure 20. — Log consumption by economic area, Douglas-fir region, 1966.

Table 5. — Log consumption by economic area and type of plant, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

Economic area by district	Type of plant									
	Shake and shingle	Sawmills[1]					Veneer	Veneer and plywood[2]	Pulp	Total
		D	C	B	A	Total				
Puget Sound:										
Bellingham	13,650	15,920	42,959	--	--	58,879	--	58,254	183,696	314,479
Port Angeles	29,764	17,540	--	--	30,000	47,540	10,000	39,749	227,710	354,763
Seattle	5,300	58,705	58,641	124,000	452,000	693,346	3,080	109,915	323,839	1,135,480
Tacoma	13,508	45,594	143,981	140,800	194,274	524,649	134,200	146,218	116,100	934,675
District total	62,222	137,759	245,581	264,800	676,274	1,324,411	147,280	354,136	851,345	2,739,397
Columbia River:										
Aberdeen	46,318	10,040	18,818	27,000	237,608	293,466	--	58,613	200,789	599,186
Longview	8,308	28,850	21,729	34,906	363,790	449,275	--	94,821	142,368	694,772
Astoria	1,878	12,459	11,000	107,543	34,289	165,291	--	94,532	--	261,701
Portland	123	65,176	191,239	218,041	426,759	901,215	78,155	265,804	231,029	1,476,326
Salem	--	4,200	40,516	180,023	56,500	281,239	26,516	166,416	--	474,171
Corvallis	--	18,364	104,878	85,060	223,492	431,794	103,124	289,334	--	824,252
Eugene	9,000	23,075	163,265	219,413	494,665	900,418	240,158	544,209	--	1,693,785
District total	65,627	162,164	551,445	871,986	1,837,103	3,422,698	447,953	1,513,729	574,186	6,024,193
Southwest Oregon:										
Roseburg	--	8,752	84,823	247,252	81,600	422,427	245,366	241,906	--	909,699
Coos Bay	--	4,176	46,185	131,202	359,631	541,194	104,881	396,099	62,661	1,104,835
Medford	--	33,000	20,599	277,903	194,867	526,369	69,436	225,508	--	821,313
District total	--	45,928	151,607	656,357	636,098	1,489,990	419,683	863,513	62,661	2,835,847
Northwest California:										
Eureka	500	1,500	288,349	613,579	815,397	1,718,825	173,528	227,053	--	2,119,906
Total, Douglas-fir region	128,349	347,351	1,236,982	2,406,722	3,964,872	7,955,927	1,188,144	2,958,431	1,488,192	13,719,343

[1] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8 hour shift, B = 80,000-119,000, C = 40,000-79,000, D = less than 40,000*

[2] *Integrated operations producing both veneer and plywood*

1966 — Eugene, Portland, Seattle, and Coos Bay. Each of these areas has a well-established forest industry with lumber and plywood firms accounting for most of the log consumption. In the Eugene, Portland, and Seattle areas, pulpmills also played an important part.

At the opposite extreme, the Astoria and Bellingham areas formed the smallest timber markets, consuming only 262 million board feet and 314 million board feet, respectively, or 1.9 percent and 2.3 percent of the region's total log consumption. Neither of these two areas has a well-developed or diversified forest industry.

Three of the region's leading log markets, Eureka, Eugene, and Coos Bay, were rated as heavily timber dependent. In each of these areas, manufacturing employment is mainly in the forest industries, and the forest industries accounted for the largest portion of employment involved in producing goods for export. In the Portland area, there is a more diversified and a wider manufacturing base, and, although the area is a large market for logs and consequently has a large amount of forest industry employment, such employment forms a much smaller portion of total export producing employment. Thus the Portland area was rated as only moderately timber dependent. Conversely, the small Astoria log market was classified as highly timber dependent. The limited amount of forest industry in the area provides the area's major employment producing goods for export because of the limited amount of other manufacturing employment located in the Astoria area.

Lumber industry major log user; consumes 58.0 percent of region's supply

The region's sawmills reported using 7,956 million board feet of logs, or 58.0 percent of all logs consumed in the region during 1966 (table 5, fig. 21). The Eureka area's lumber

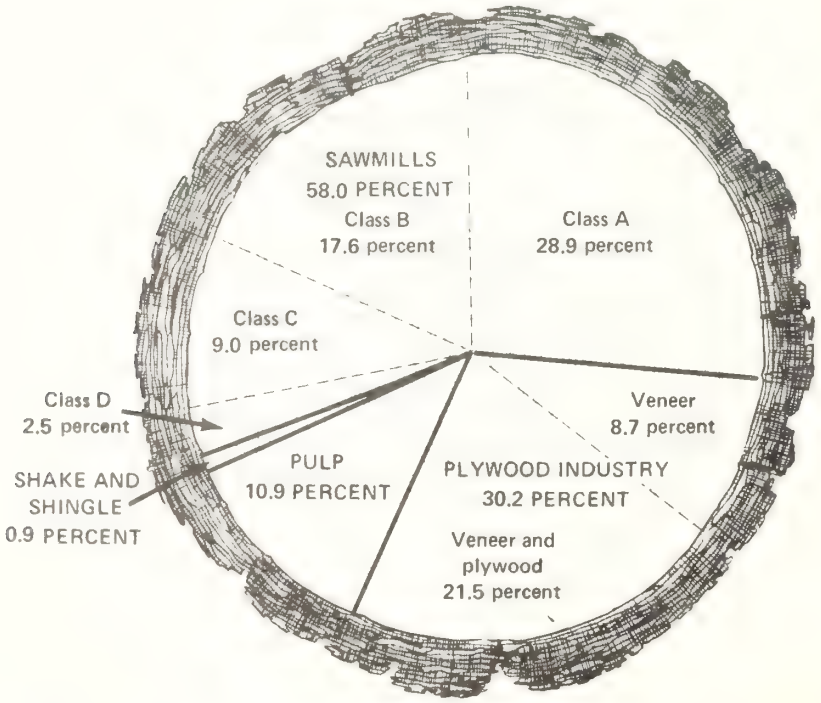
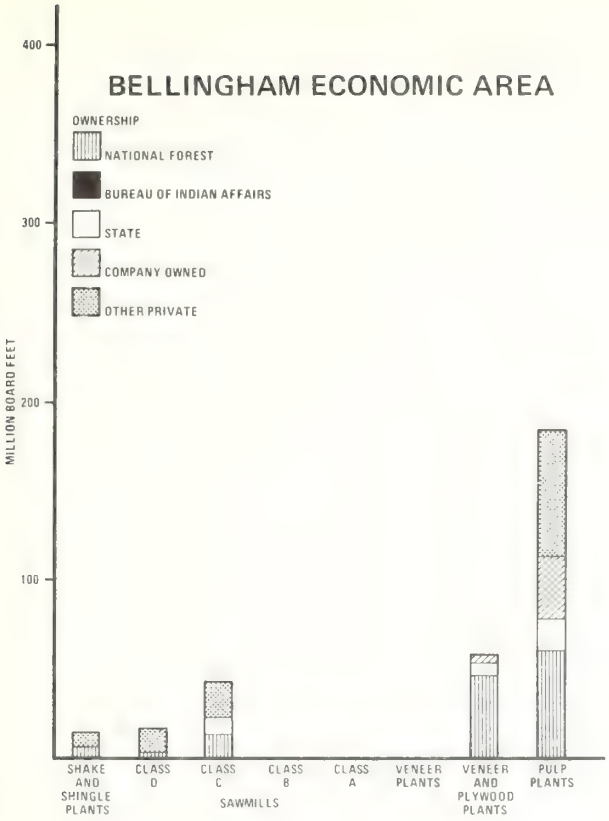


Figure 21. — How the region's forest industry shared the timber harvest. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.



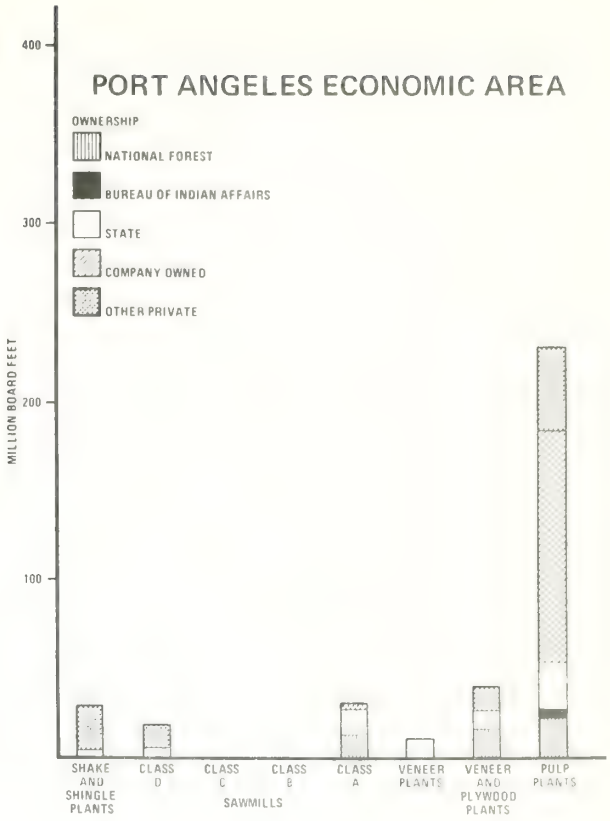
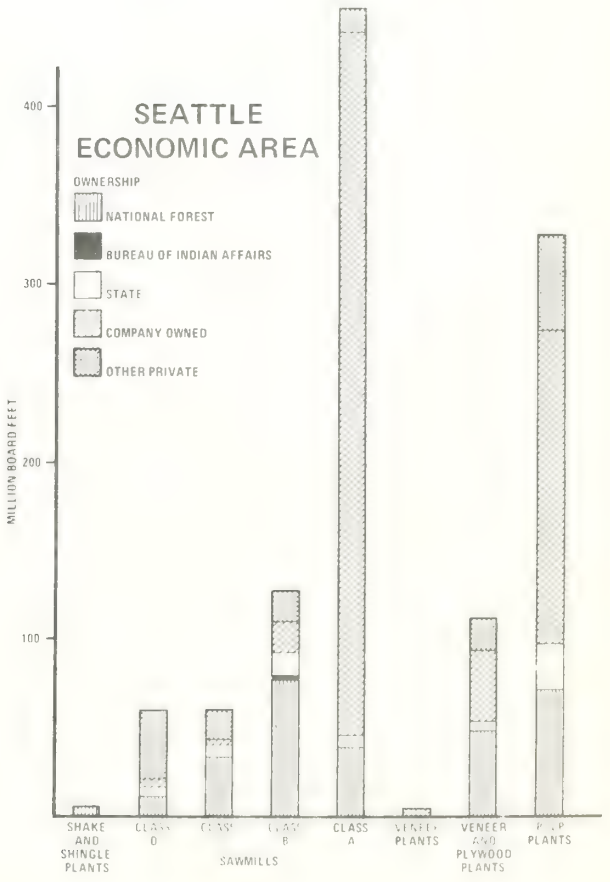
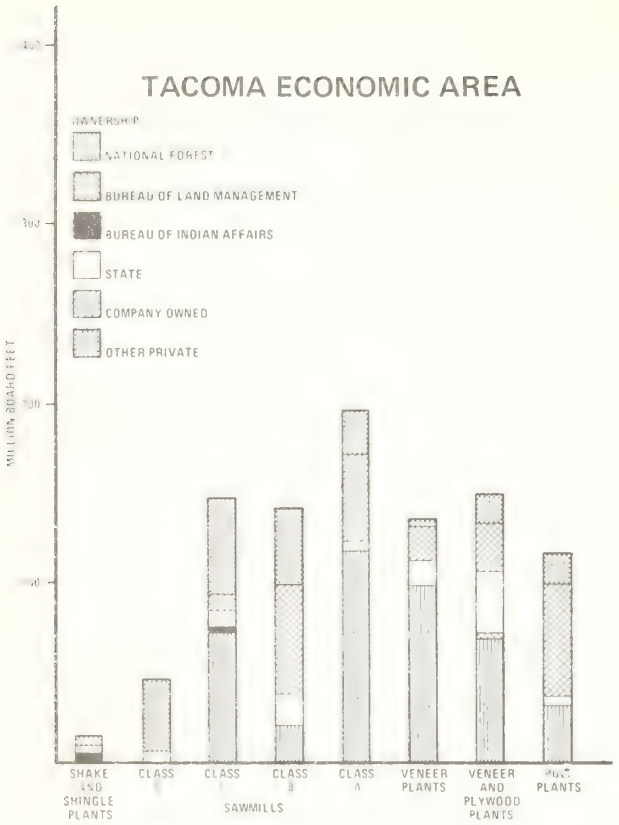


Figure 22. — Consumption of logs from each ownership class by plant type and economic area, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.




TACOMA ECONOMIC AREA
OWNERSHIP
NATIONAL FOREST
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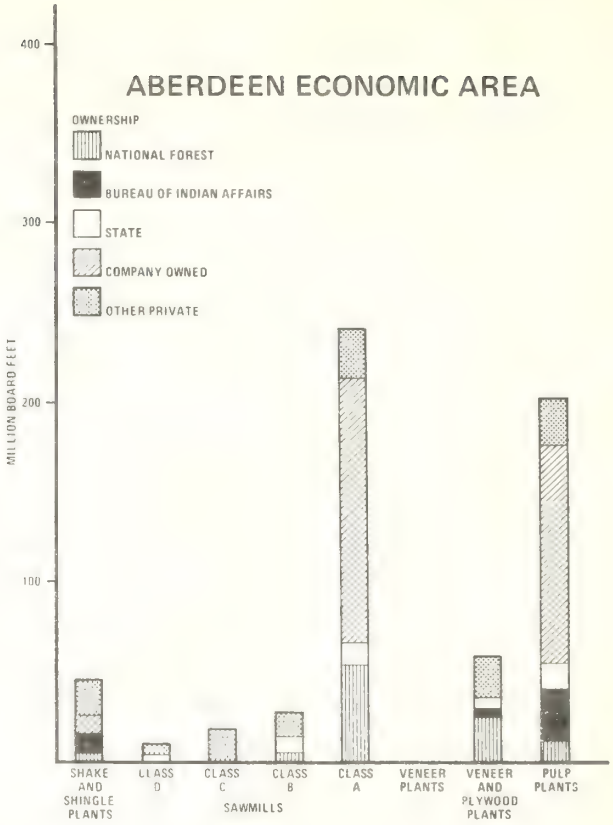
STATE
COMPANY OWNED
OTHER PRIVATE
MILLION BOARD FEET
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS


ABERDEEN ECONOMIC AREA
OWNERSHIP
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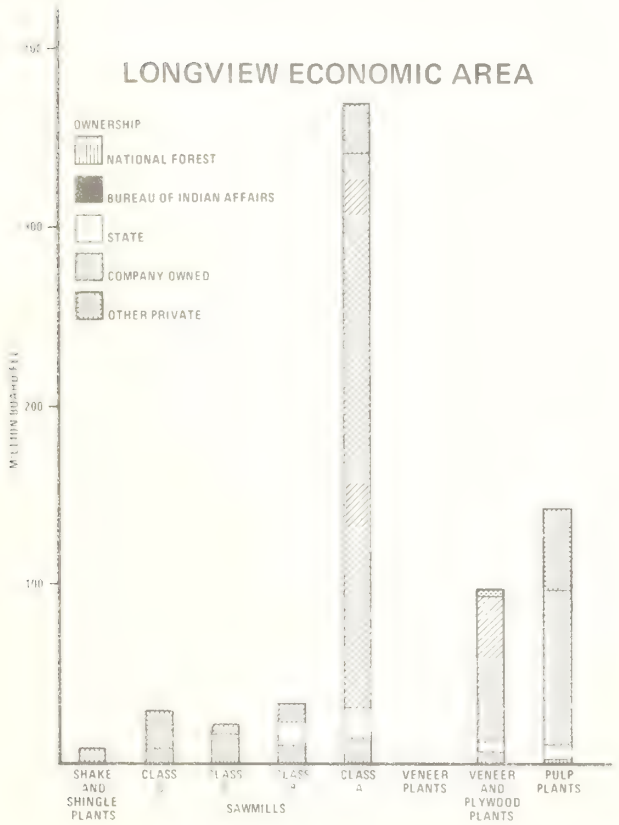
COMPANY OWNED
OTHER PRIVATE
MILLION BOARD FEET
400
300
200
100
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS


LONGVIEW ECONOMIC AREA
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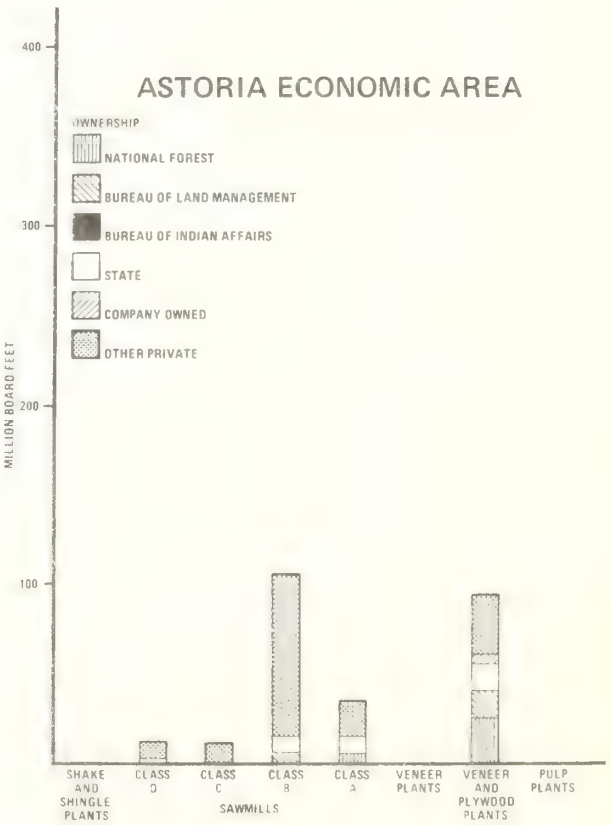
SAWMILLS


ASTORIA ECONOMIC AREA
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OTHER PRIVATE
MILLION BOARD FEET
400
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200
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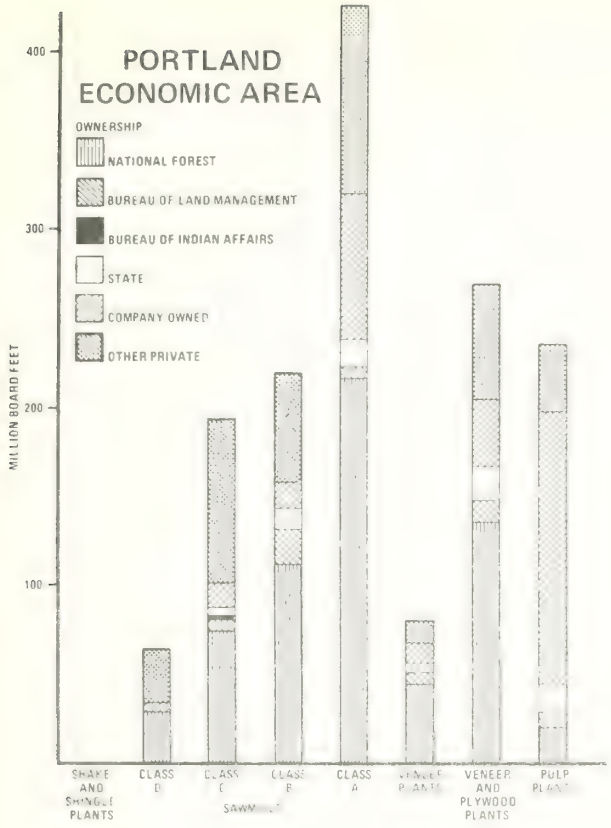
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS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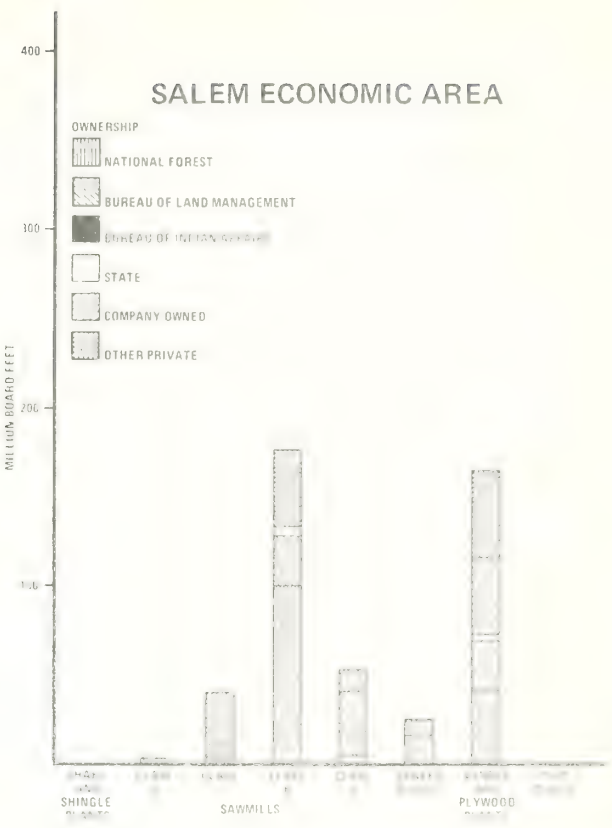
OWNERSHIP
NATIONAL FOREST
BUREAU OF LAND MANAGEMENT
BUREAU OF INDIAN AFFAIRS
STATE
COMPANY OWNED
OTHER PRIVATE
MILLION BOARD FEET
400
300
200
100
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS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STATE
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MILLION BOARD FEET
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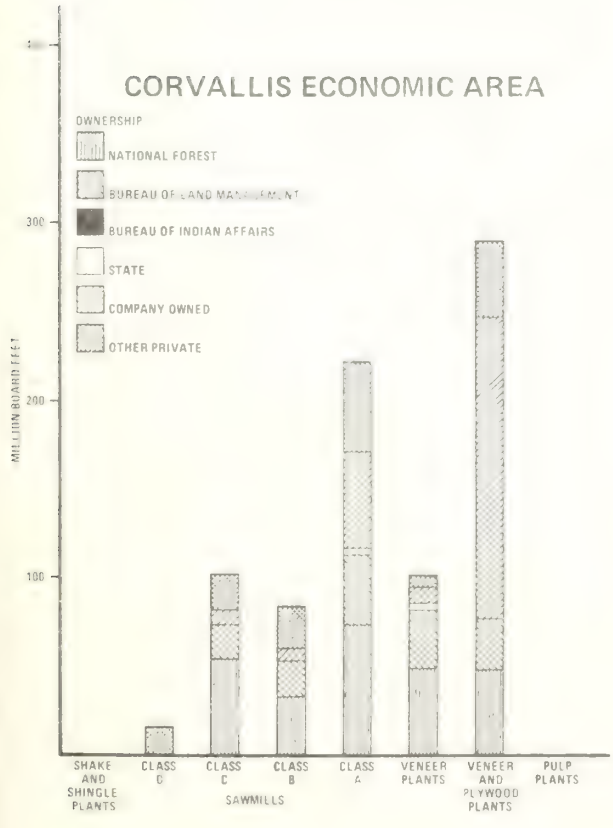
SHINGLE
SAWMILLS
PLYWOOD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STATE
COMPANY OWNED
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MILLION BOARD FEET
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SHAKE AND SHINGLE PLANTS
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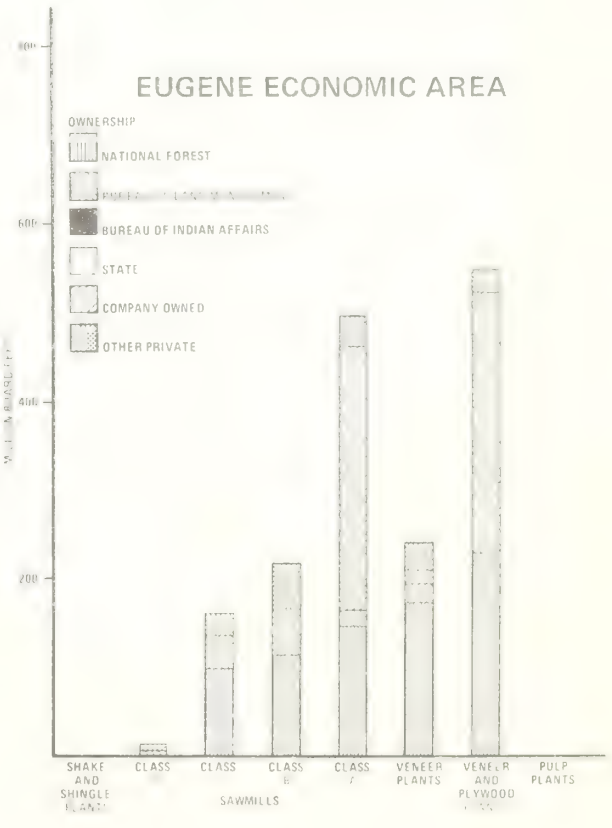
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS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NATIONAL FOREST
BUREAU OF INDIAN AFFAIRS
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COMPANY OWNED
OTHER PRIVATE
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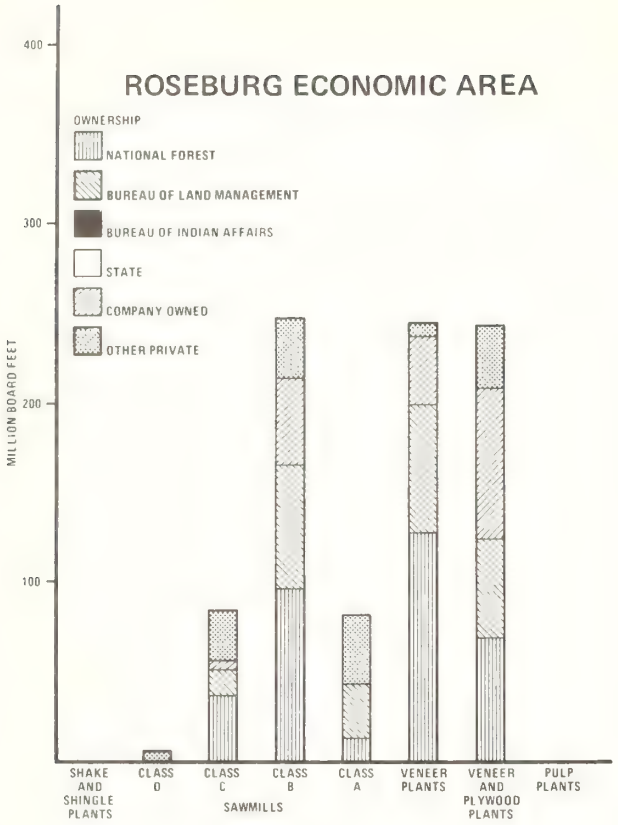
CLASS
VENEER PLANTS
PULP PLANTS
SAWMILLS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NATIONAL FOREST
BUREAU OF LAND MANAGEMENT
BUREAU OF INDIAN AFFAIRS
STATE
COMPANY OWNED
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MILLION BOARD FEET
400
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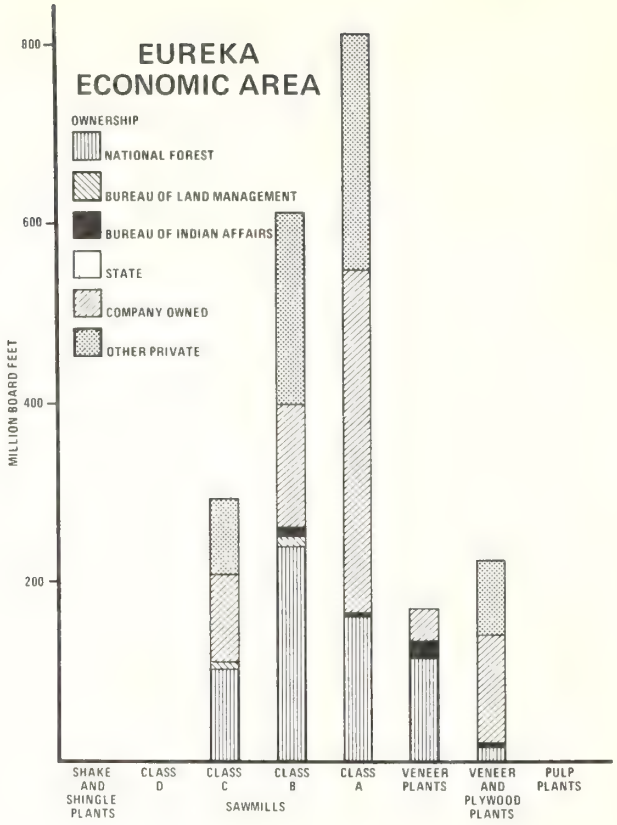
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS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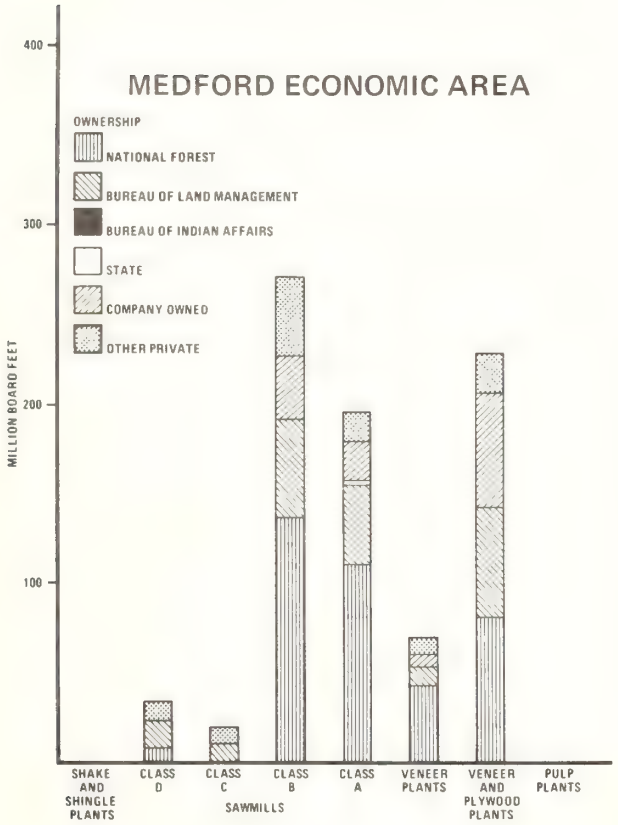
OWNERSHIP
NATIONAL FOREST
BUREAU OF LAND MANAGEMENT
BUREAU OF INDIAN AFFAIRS
STATE
COMPANY OWNED
OTHER PRIVATE
MILLION BOARD FEET
800
600
400
200
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS


MEDFORD ECONOMIC AREA
OWNERSHIP
NATIONAL FOREST
BUREAU OF LAND MANAGEMENT
BUREAU OF INDIAN AFFAIRS
STATE
COMPANY OWNED
OTHER PRIVATE
MILLION BOARD FEET
400
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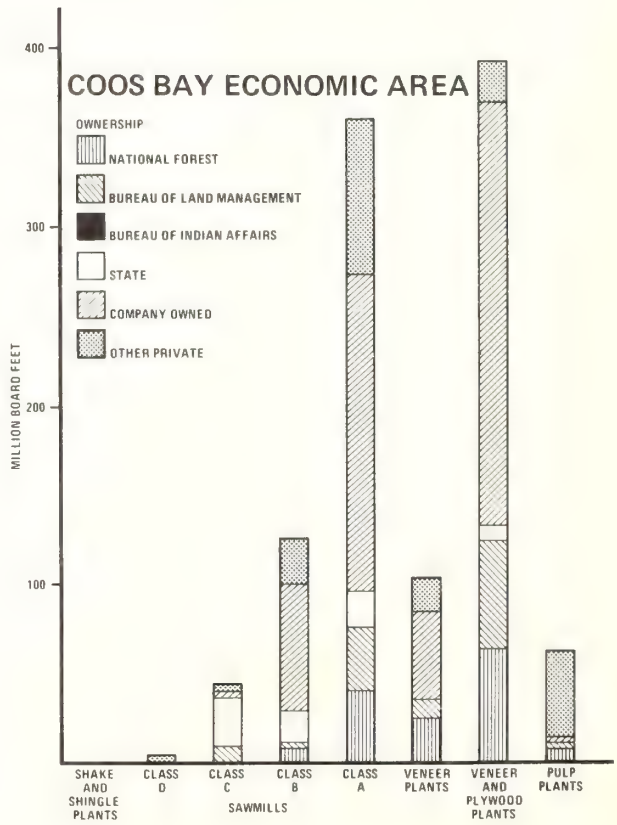
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS


COOS BAY ECONOMIC AREA
OWNERSHIP
NATIONAL FOREST
BUREAU OF LAND MANAGEMENT
BUREAU OF INDIAN AFFAIRS
STATE
COMPANY OWNED
OTHER PRIVATE
MILLION BOARD FEET
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100
SHAKE AND SHINGLE PLANTS
CLASS D
CLASS C
CLASS B
CLASS A
VENEER PLANTS
VENEER AND PLYWOOD PLANTS
PULP PLANTS
SAWMILLS

industry was the largest saw-log user, consuming 21.6 percent of the region's saw logs. The major saw-log consuming areas were the same as the major markets for all logs, namely Eureka, Portland, Eugene, Seattle, and Coos Bay. The consumption of saw logs was smallest in the Port Angeles and Bellingham areas. Figure 22 presents each area's log consumption pattern by mill type.

There was not much difference in the region between percents of 8-hour shift capacity and of total saw logs consumed by each class mill. The tabulation below shows the variation between classes:

Class	Percent of sawmill 8-hour shift capacity	Percent of saw logs consumed
A	44.7	49.8
B	29.6	30.3
C	18.8	15.5
D	6.9	4.4
Total	100.0	100.0

With the seasonal type of operation found in many of the smaller mills and the operation of more than one shift by some of the larger mills, it was expected that large mills would consume a much higher portion of the region's saw logs relative to the proportion of 8-hour shift capacity they represent. This is apparently not true. The weak lumber market, especially during the last half of 1966, may partially explain the findings. Many of the seasonal operations may have been shut down at the time the study was conducted, thus lowering the percent of total capacity of class D mills accounted for. In addition, the incidence of double shift operations may not be any larger for mills in the larger size classes than in the other classes.

Plywood industry utilizes 30.2 percent of region's timber

The Douglas-fir region's plywood industry utilized 4,147 million board feet of logs in 1966, 30.2 percent of the region's total log consumption (table 5, fig. 21). Veneer operations used 1,188 million board feet of logs or 8.7 percent of the total log volume, and integrated veneer and plywood operations (producing both veneer and plywood) accounted for 2,958 million board feet or 21.5 percent of total regional log consumption. The centers of the region's plywood industry are the Eugene and Coos Bay areas, which use 31.8 percent of the logs going to integrated veneer and plywood plants and 29.0 percent of all logs going to veneer plants. The Eugene area accounted for 18.4 percent of the logs consumed by the integrated veneer and plywood plants, followed by Coos Bay with 13.4 percent. Veneer plant log consumption was largest in the Roseburg area, between the Eugene and Coos Bay areas, with 20.6 percent, and in Eugene with 20.2 percent of the total. In general, log consumption followed the same pattern as plywood production.

Pulp plants utilize 1,488 million board feet of logs, 10.9 percent of regional total

Pulp plants reported consuming 1,488 million board feet of logs in 1966, 10.9 percent of the total log volume (table 5, fig. 22). The Seattle area was the largest log consumer; its pulp plants used 324 million board feet. Only eight areas reported log consumption by pulpmills (fig. 18). The percent of pulp capacity operating on logs varied throughout the region — western Washington pulp plants used logs for 55 percent of their raw material input as compared with 13 percent for western Oregon plants (table 6). California had only two plants, both operating entirely on chips. In western Washington, the Aberdeen economic area pulpmills operated 81 percent on logs; Bellingham used 79 percent logs; and Seattle, 84 percent. One exception to low log use in Oregon was the Coos Bay area where logs made up 98 percent of pulpwood inputs.

Comparison of pulp capacity operating on roundwood shown in this study with that presented by Guthrie and Iulo[11] based on a wood supply survey conducted by Arthur Anderson and Company for 1960 reveals a greater reli-

[11] *Guthrie, John A., and Iulo, William. Some economic aspects of the pulp and paper industry, prepared under the sponsorship of the Northwest Pulp and Paper Association, Seattle, Washington. 106 pp., illus. 1963.*

Table 6. — Percent of pulp capacity operating on logs by economic area, Douglas-fir region, 1960 and 1966

Economic areas by district	1960[1]	1966
Puget Sound:		
Bellingham	52.4	84.2
Port Angeles	55.4	60.0
Seattle	58.0	76.0
Tacoma	71.4	47.0
Columbia River:		
Aberdeen	72.4	81.0
Longview	74.6	16.0
Astoria	--	--
Portland	73.0	31.0
Salem	([2])	0
Corvallis	([2])	0
Eugene	([2])	0
Southwest Oregon:		
Roseburg	([3])	0
Coos Bay	([2])	98.0
Medford	--	--
Northwest California:		
Eureka	([3])	0

[1] *Guthrie, John A., and Iulo, William. Some economic aspects of the pulp and paper industry. Prepared under the sponsorship of the Northwest Pulp and Paper Association, Seattle, Washington, May 1963. Data converted from value figures.*

[2] *Salem, Corvallis, Eugene, and Coos Bay areas combined, operated 36 percent on logs in 1960 and 8 percent in 1966. Of these areas, only Coos Bay used logs in 1966.*

[3] *Data not available.*

ance on roundwood in the Puget Sound district and a lesser use of logs throughout western Oregon in 1966 (table 6). This may be an indication that in the Puget Sound area second-growth timber is being increasingly utilized for pulp. In Oregon, the increased use of chips is an indication of the increased utilization of all forest products which is taking place.

Shake and shingle plant log use totals 128 million board feet

Shake and shingle operations contacted in this study consumed 128 million board feet of logs in 1966, representing only 0.9 percent of the region's total log consumption (table 5, fig. 21). The pattern closely followed the distribution of shake and shingle capacity, with the Aberdeen area the major consumer.

REGIONAL LOG FLOWS

Log movement in region limited

Logs are bulky and costly to transport, and the region's forest industry generally obtained its log supplies from within the same area in which the industry was located (table 7). This is especially true in the areas rated as highly timber dependent. The Roseburg, Port Angeles, and Eureka areas, all so rated, were the region's most self-sufficient timber areas, each obtaining over 96 percent of the logs used by its forest industry from within its own boundaries. In general, the more timber dependent the area's economy was, the more self-

Table 7. — Flow of logs by economic ar region, 1966

(Thousand board fe

Economic area of log origin	Bellingham	Port Angeles	Seattle	Tacoma	Aberdeen	Longview	Econom Astoria
Bellingham	204,485	795	126,759	4,992	--	--	--
Port Angeles	15,000	342,136	51,402	22,347	32,356	--	--
Seattle	54,745	5,100	502,689	24,976	--	--	--
Tacoma	9,500	6,300	373,882	690,777	8,132	158,897	--
Aberdeen	--	432	5,000	97,614	555,725	70,859	--
Longview	--	--	5,000	24,632	2,973	377,522	32,063
Astoria	--	--	--	676	--	1,054	179,634
Portland	--	--	1,325	49,796	--	86,020	17,124
Salem	--	--	--	--	--	--	--
Corvallis	--	--	--	18,000	--	--	31,434
Eugene	--	--	--	--	--	--	1,445
Roseburg	--	--	--	--	--	--	--
Coos Bay	--	--	--	--	--	--	--
Medford	--	--	--	--	--	--	--
Eureka	--	--	--	--	--	--	--
Eastern Washington	--	--	52,566	864	--	420	--
Eastern Oregon	--	--	--	--	--	--	--
Other California	--	--	--	--	--	--	--
Canada and Idaho	30,750	--	16,859	--	--	--	--
Total	314,480	354,763	1,135,482	934,674	599,186	694,772	261,700

[1] *Totals may not agree with previous tables due to rounding.*

sufficient was the area in terms of timber supply (fig. 23). The Longview area was the only area with a highly timber dependent economy that obtained less than 60 percent of its needed log supplies from within its own borders; this can be attributed to the relative ease of moving logs on the nearby Columbia River.

The generally limited amount of log movement within the region is illustrated by the fact that nine of the region's 15 economic areas obtained over 70 percent of their log requirements from their respective areas. Only one area, Salem, reported obtaining over 50 percent of the logs utilized by its forest industry from outside the area.

Some of the logs consumed in the Douglas-fir region in 1966 came from outside the region. In total, 47.6 million board feet were imported from Canada and Idaho, with about two-thirds of this volume going to the Bellingham area and the remainder to Seattle area plants. The Seattle area was also the major west-side consumer for eastern Washington logs, using 52.6 million board feet or 97 percent of all eastern Washington logs consumed in western Washington. The Medford area was a market for 57.8 million board feet of eastern Oregon logs, and a small volume of eastern Oregon logs also went to the Portland and Eugene areas.

Seattle area is region's leading log importer

Although the Salem area forest industry imported a larger percentage of its logs than any other area in the region (67.6 percent),

f origin and destination, Douglas-fir

cribner log rule)

ea of log utilization								
Portland	Salem	Corvallis	Eugene	Roseburg	Coos Bay	Medford	Eureka	Total[1]
--	--	--	--	--	--	--	--	337,031
2,820	--	--	--	--	--	--	--	466,061
--	--	--	--	--	--	--	--	587,510
42,300	--	--	--	--	--	--	--	1,289,788
46,148	--	--	--	--	--	--	--	775,778
106,488	--	--	--	--	--	--	--	548,678
236,246	20,070	--	--	--	--	--	--	437,680
394,391	39,229	5,500	--	--	--	--	--	1,093,385
34,194	153,842	47,664	--	--	--	--	--	235,700
86,906	233,935	655,927	81,433	--	--	--	--	1,107,635
6,400	27,093	115,163	1,317,400	1,901	--	--	--	1,469,402
1,600	--	--	281,067	879,661	141,559	92,141	--	1,396,028
--	--	--	9,382	21,121	956,498	8,852	19,760	1,015,613
3,200	--	--	--	7,015	1,616	620,600	2,373	634,804
--	--	--	--	--	5,161	41,924	2,048,728	2,095,813
314	--	--	--	--	--	--	--	54,164
15,321	--	--	4,500	--	--	57,796	--	77,617
--	--	--	--	--	--	--	49,045	49,045
--	--	--	--	--	--	--	--	47,609
1,176,328	474,169	824,254	1,693,782	909,698	1,104,834	821,313	2,119,906	13,719,341

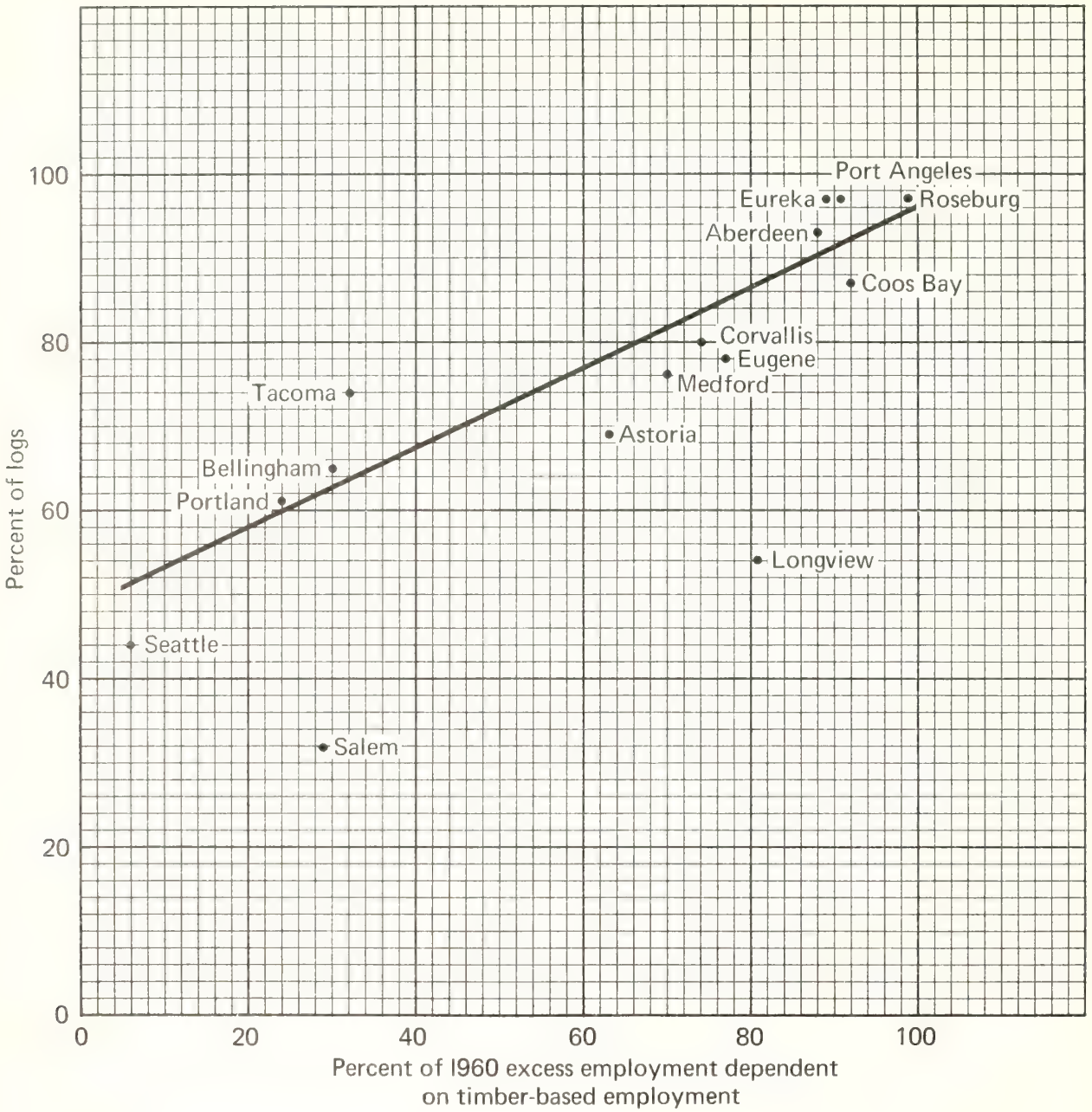


Figure 23. — Relationship of an area's timber dependency to the percent of logs obtained from within the area, Douglas-fir region.

the Seattle area mills imported the largest volume (table 8). Seattle firms imported 632.8 million board feet in 1966, 55.7 percent of the area's log needs. These logs came from 6 other economic areas as well as eastern Washington, Canada, and Idaho. Portland, the second largest log importer (39.4 percent) in the region, obtained logs from 10 other economic areas as well as eastern Washington and eastern Oregon, making Portland the most diversified area in terms of geographical sources of timber.

Table 8. — Volume of logs imported and exported by economic area, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

Economic areas by district	Volume imported	Volume exported[1]	Net balance
Puget Sound:			
Bellingham	109,995	132,546	—22,551
Port Angeles	12,627	123,925	—111,298
Seattle	632,793	84,821	547,972
Tacoma	243,897	599,011	—335,114
District total	999,312	940,303	59,009
Columbia River:			
Aberdeen	43,461	220,053	—176,592
Longview	317,250	171,156	146,094
Astoria	82,066	258,046	—175,980
Portland	581,937	198,994	382,943
Salem	320,327	81,858	238,469
Corvallis	168,327	451,708	—283,381
Eugene	376,382	152,002	224,380
District total	1,889,750	1,533,817	355,933
Southwest Oregon:			
Roseburg	30,037	516,367	—486,330
Coos Bay	148,336	59,115	89,221
Medford	200,713	14,204	186,509
District total	379,086	589,686	—210,600
Northwest California:			
Eureka	71,178	47,085	24,093

[1] *Does not include log volumes exported out of the region.*

The Portland and Seattle areas were large importers of timber due to their large forest industry concentrations and their need to go outside their predominantly urbanized areas for stumpage. Concentrations of specialty mills within these areas, such as mills operating only on large cull logs, also tend to widen the distance firms must range for their specialized log requirements. Finally, both areas have large concentrations of log-using pulp capacity which tends to have a wider area of raw material procurement than other wood products industries.

Tacoma area largest interarea log exporter

The Tacoma economic area shipped 599.0 million board feet of logs to the forest industries located in other economic areas during 1966, with over half the shipments going to Seattle. Roseburg was second in interarea exports, shipping 516.4 million board feet, of which more than half went to the neighboring Eugene area. Seven of the region's economic areas were net exporters, and the other eight, net importers.

LANDOWNERSHIP AND TIMBER SUPPLY

Private lands supplied 55.1 percent of region's log requirements

Private timberlands were the forest industries' main source of supply, furnishing 55.1 percent of all logs used in 1966 (table 9, fig. 24). Private logs purchased[12] by mill operators accounted for 22.0 percent of the total and logs from company owned or managed lands, the remaining 33.1 percent.

The forest industry in the Eureka area was the largest user of private logs, 1,418.7 million board feet or 18.7 percent of all private logs used in the region. The Longview area forest industry, however, relied most heavily on private logs, obtaining 85.4 percent of its total supply from private sources (table 10). Over 68 percent of the total volume of logs used by the Longview forest industry came from company owned or managed lands. This

[12] *Purchased logs from other private sources may be either from forest industry or other private landowning classes.*

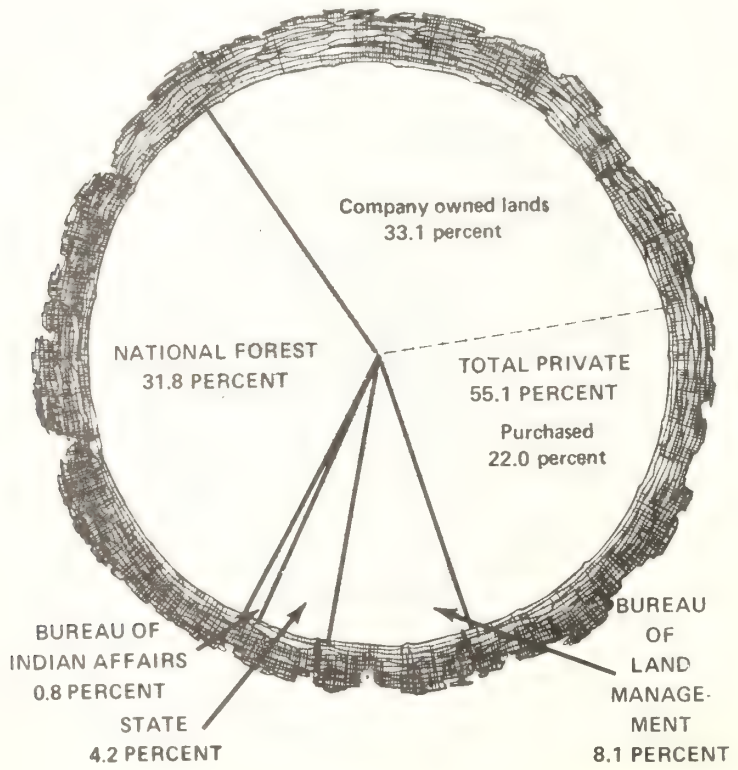


Figure 24. — Source of logs used by the region's forest industry, 1966.

Table 9. — Volume of timber used from each timber ownership class, by economic area, Douglas-fir region, 1966
(Thousand board feet, Scribner log rule)

Economic area by district	National Forest	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private[1]	Total
Puget Sound:							
Bellingham	127,655	--	2,430	34,437	38,175	111,782	314,479
Port Angeles	50,792	--	5,796	66,315	131,686	100,174	354,763
Seattle	277,789	--	2,911	62,214	631,764	160,802	1,135,480
Tacoma	403,897	3,000	8,345	92,846	226,149	200,438	934,675
District total	860,133	3,000	19,482	255,812	1,027,774	573,196	2,739,397
Columbia River:							
Aberdeen	97,707	-	45,614	44,423	277,315	134,127	599,186
Longview	52,783	480	--	48,084	472,904	120,521	694,772
Astoria	32,472	21,752	--	34,998	6,223	166,256	261,701
Portland	615,970	62,558	3,850	70,142	313,947	409,859	1,476,326
Salem	168,839	72,871	--	12,708	72,333	147,420	474,171
Corvallis	256,740	143,179	--	12,734	248,357	163,242	824,252
Eugene	762,931	214,831	--	5,708	528,718	181,597	1,693,785
District total	1,987,442	515,671	49,464	228,797	1,919,797	1,323,022	6,024,193
Southwest Oregon:							
Roseburg	341,440	241,348	--	2,762	173,672	150,477	909,699
Coos Bay	155,511	124,248	--	79,749	535,921	209,406	1,104,835
Medford	377,689	203,622	--	2,685	125,467	111,850	821,313
District total	874,640	569,218	--	85,196	835,060	471,733	2,835,847
Northwest California:							
Eureka	637,984	21,120	42,074	--	764,185	654,543	2,119,906
Total, Douglas-fir region	4,360,199	1,109,009	111,020	569,805	4,546,816	3,022,494	13,719,343

[1] *Other private timber consists of purchased timber volumes from forest industry or other private landowning classes.*

was the largest portion of logs used from one source by any economic area.

In addition to Longview, six other areas obtained over 65 percent of their log requirements from private lands: Aberdeen, Coos Bay, Seattle, Eureka, Astoria, and Port Angeles. All these areas but Seattle are classified as having economies strongly dependent on forest-based employment. The importance of private timber throughout the region is further evidenced by the fact that only two areas, Roseburg and Medford, received less than 40 percent of their timber supply from private lands.

The region's lumber industry was the major consumer of logs from private sources, using 4,513 million board feet, or 59.6 percent of all private logs. This was followed by the plywood industry which used 24.7 percent and the pulp industry which used 14.6 percent (table 11, fig. 25). Distribution of company owned timber was as follows: 54.4 percent to sawmills, mainly to large class A mills, 28.7 percent to the plywood industry, and 16.7 percent to pulp plants (fig. 26). Purchased private timber was also consumed more heavily by the sawmills which used 67.4 percent of the total.

National Forests furnished 4,360 million board feet of logs, 31.8 percent of region's total

The Douglas-fir region's forest industry reported using 4,360 million board feet of Na-

Table 10. — Percent of timber used in economic areas from each timber ownership class, Douglas-fir region, 1966

Economic areas by district	National Forest	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private[1]	Total
Puget Sound:							
Bellingham	40.6	--	0.8	11.0	12.1	35.5	100.0
Port Angeles	14.3	--	1.6	18.7	37.1	28.3	100.0
Seattle	24.5	--	.2	5.5	55.6	14.2	100.0
Tacoma	43.2	0.3	.9	9.9	24.2	21.5	100.0
District total	31.4	.1	.7	9.4	37.5	20.9	100.0
Columbia River:							
Aberdeen	16.3	--	7.6	7.4	46.3	22.4	100.0
Longview	7.6	.1	--	6.9	68.1	17.3	100.0
Astoria	12.4	8.3	--	13.4	2.4	63.5	100.0
Portland	41.7	4.2	.3	4.7	21.3	27.8	100.0
Salem	35.6	15.4	--	2.7	15.2	31.1	100.0
Corvallis	31.1	17.4	--	1.6	30.1	19.8	100.0
Eugene	45.1	12.7	--	.3	31.2	10.7	100.0
District total	33.0	8.5	.8	3.8	31.9	22.0	100.0
Southwest Oregon:							
Roseburg	37.5	26.5	--	.3	19.1	16.6	100.0
Coos Bay	14.1	11.2	--	7.2	48.5	19.0	100.0
Medford	46.0	24.8	--	.3	15.3	13.6	100.0
District total	30.8	20.1	--	3.0	29.5	16.6	100.0
Northwest California:							
Eureka	30.1	1.0	2.0	--	36.0	30.9	100.0
Total, Douglas-fir region	31.8	8.1	.8	4.2	33.1	22.0	100.0

[1] *Other private timber consists of purchased volumes from forest industry or other private landowning classes.*

tional Forest logs in 1966, 31.8 percent of all logs utilized in domestic production that year.

The Eugene area's forest industry was the region's largest market for Forest Service timber, consuming over 760 million board feet, or 17.5 percent of the region's total consumption of National Forest logs. The Eugene area was followed by the Eureka and Portland areas, each using over 600 million board feet of National Forest logs.

National Forest timber was the most important source of logs for the Eugene and Medford areas. The wood used in these areas was, respectively, 45.1 and 46.0 percent National Forest logs. These two areas were the only areas classified as having highly timber-dependent economies, on the basis of timber-based employment, that received more than 40 percent of their timber supplies from the National Forests. In four of the region's areas

Table 11. — Volume of logs used from each ownership source, by type of plant and economic area, Douglas-fir region, 1966
(Thousand board feet, Scribner log rule)

Plant type	National Forest Administration	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private [1]	Total
TOTAL, ALL ECONOMIC AREAS							
Shake and shingle	16,659	1,800	15,553	9,450	11,129	73,758	128,349
Sawmills[2]							
D	61,863	25,913	1,337	24,310	20,087	213,841	347,351
C	497,154	110,153	8,943	63,660	139,891	417,181	1,236,982
B	959,733	271,685	12,000	96,418	395,882	671,004	2,406,722
A	999,631	191,655	7,900	110,819	1,918,871	735,996	3,964,872
Total	2,518,381	599,406	30,180	295,207	2,474,731	2,038,022	7,955,927
Veneer	683,285	153,559	20,437	35,711	185,144	110,308	1,188,444
Veneer and plywood[3]	918,431	342,125	10,450	113,233	1,118,636	455,556	2,958,431
Pulp	223,443	12,119	34,400	116,204	757,176	344,850	1,488,192
Total	4,360,199	1,109,009	111,020	569,805	4,546,816	3,022,494	13,719,343
BELLINGHAM ECONOMIC AREA							
Shake and shingle	4,535	--	--	1,488	--	7,627	13,650
Sawmills[2]							
D	2,850	--	130	260	110	12,570	15,920
C	13,678	--	1,300	8,196	--	19,785	42,959
B	--	--	--	--	--	--	--
A	--	--	--	--	--	--	--
Total	16,528	--	1,430	8,456	110	32,355	58,879
Veneer	--	--	--	--	--	--	--
Veneer and plywood[3]	46,429	--	--	7,460	4,000	365	58,254
Pulp	60,163	--	1,000	17,033	34,065	71,435	183,696
Total	127,655	--	2,430	34,437	38,175	111,782	314,479
PORT ANGELES ECONOMIC AREA							
Shake and shingle	1,363	--	--	2,331	150	25,920	29,764
Sawmills[2]							
D	90	--	576	4,151	20	12,703	17,540
C	--	--	--	--	--	--	--
B	--	--	--	--	--	--	--
A	12,000	--	--	13,500	1,500	3,000	30,000
Total	12,090	--	576	17,651	1,520	15,703	47,540
Veneer	--	--	--	10,000	--	--	10,000
Veneer and plywood[3]	15,900	--	--	9,937	1,987	11,925	39,749
Pulp	21,439	--	5,220	26,396	128,029	46,626	227,710
Total	50,792	--	5,796	66,315	131,686	100,174	354,763

See footnotes at end of table.

continued

Table 11. — Volume of logs used from each ownership source, by type of plant and economic area, Douglas-fir region, 1966 (continued)
(Thousand board feet, Scribner log rule)

Plant type	National Forest Administration	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private[1]	Total
SEATTLE ECONOMIC AREA							
Shake and shingle	3,375	--	--	875	--	1,050	5,300
Sawmills[2]							
D	10,828	--	11	5,580	4,962	37,324	58,705
C	32,404	--	–	6,657	2,400	17,180	58,641
B	75,000	--	2,000	12,000	18,000	17,000	124,000
A	38,690	--	900	7,200	391,000	14,210	452,000
Total	156,922	--	2,911	31,437	416,362	85,714	693,346
Veneer	--	--	--	--	--	3,080	3,080
Veneer and plywood[3]	47,216	--	--	4,200	39,822	18,677	109,915
Pulp	70,276	--	--	25,702	175,580	52,281	323,839
Total	277,789	--	2,911	62,214	631,764	160,802	1,135,480
TACOMA ECONOMIC AREA							
Shake and shingle	358	--	4,125	3,995	--	5,030	13,508
Sawmills[2]							
D	350	--	620	5,810	1,620	37,194	45,594
C	69,601	--	3,600	8,270	9,443	53,067	143,981
B	20,950	--	--	16,820	60,290	42,740	140,800
A	116,044	--	--	4,960	48,695	24,575	194,274
Total	206,945	--	4,220	35,860	120,048	157,576	524,649
Veneer	97,800	--	--	13,720	18,250	4,430	134,200
Veneer and plywood[3]	67,603	3,000	--	33,466	26,133	16,016	146,218
Pulp	31,191	--	--	5,805	61,718	17,386	116,100
Total	403,897	3,000	8,345	92,846	226,149	200,438	934,675
ABERDEEN ECONOMIC AREA							
Shake and shingle	3,374	--	11,428	740	10,973	19,803	46,318
Sawmills[2]							
D	500	--	--	3,000	500	6,040	10,040
C	--	--	1,443	--	--	17,375	18,818
B	5,400	--	--	8,100	--	13,500	27,000
A	52,250	--	--	12,302	144,400	28,656	237,608
Total	58,150	--	1,443	23,402	144,900	65,571	293,466
Veneer	--	--	--	--	--	--	--
Veneer and plywood[3]	24,970	--	4,563	5,910	1,130	22,040	58,613
Pulp	11,213	--	28,180	14,371	120,312	26,713	200,789
Total	97,707	--	45,614	44,423	277,315	134,127	599,186

See footnotes at end of table. *continued*

Table 11. — Volume of logs used from each ownership source, by type of plant and economic area, Douglas-fir region, 1966 (continued)
(Thousand board feet, Scribner log rule)

Plant type	National Forest Administration	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private [1]	Total
LONGVIEW ECONOMIC AREA							
Shake and shingle	41	--	--	21	--	8,246	8,308
Sawmills[2]							
D	6,960	480	--	1,570	1,480	18,360	28,850
C	12,000	--	--	2,442	269	7,018	21,729
B	10,472	--	--	13,962	--	10,472	34,906
A	14,088	--	--	16,500	305,702	27,500	363,790
Total	43,520	480	--	34,474	307,451	63,350	449,275
Veneer	--	--	--	--	--	--	--
Veneer and plywood[3]	6,491	--	--	5,397	79,870	3,063	94,821
Pulp	2,731	--	--	8,192	85,583	45,862	142,368
Total	52,783	480	--	48,084	472,904	120,521	694,772
ASTORIA ECONOMIC AREA							
Shake and shingle	--	--	--	--	--	1,878	1,878
Sawmills[2]							
D	--	--	--	2,000	400	10,059	12,459
C	--	--	--	--	--	11,000	11,000
B	1,844	6,268	--	8,998	--	90,433	107,543
A	5,143	--	--	9,601	--	19,545	34,289
Total	6,987	6,268	--	20,599	400	131,037	165,291
Veneer	--	--	--	--	--	--	--
Veneer and plywood[3]	25,485	15,484	--	14,399	5,823	33,341	94,532
Pulp	--	--	--	--	--	--	--
Total	32,472	21,752	--	34,998	6,223	166,256	261,701
PORTLAND ECONOMIC AREA							
Shake and shingle	13	--	--	--	6	104	123
Sawmills[2]							
D	27,859	1,600	--	--	5,502	30,215	65,176
C	71,995	6,997	2,600	4,537	13,738	91,372	191,239
B	108,314	20,574	--	11,470	14,176	63,507	218,041
A	212,697	6,440	--	15,590	81,207	110,825	426,759
Total	420,865	35,611	2,600	31,597	114,623	295,919	901,215
Veneer	43,678	6,525	--	4,935	10,715	12,302	78,155
Veneer and plywood[3]	132,239	12,200	1,250	18,645	36,978	64,492	265,804
Pulp	19,175	8,222	--	14,965	151,625	37,042	231,029
Total	615,970	62,558	3,850	70,142	313,947	409,859	1,476,326

See footnotes at end of table.

continued

Table 11. — Volume of logs used from each ownership source, by type of plant and economic area, Douglas-fir region, 1966 (continued)
(Thousand board feet, Scribner log rule)

Plant type	National Forest Administration	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private [1]	Total
SALEM ECONOMIC AREA							
Shake and shingle	--	--	--	--	--	--	--
Sawmills[2]							
D	--	--	--	--	1,527	2,673	4,200
C	3,000	3,000	--	4,150	861	29,505	40,516
B	103,986	27,350	--	4,990	1,190	42,507	180,023
A	5,650	13,560	--	--	23,730	13,560	56,500
Total	112,636	43,910	--	9,140	27,308	88,245	281,239
Veneer	15,761	--	--	--	1,065	9,690	26,516
Veneer and plywood[3]	40,442	28,961	--	3,568	43,960	49,485	166,416
Pulp	--	--	--	--	--	--	--
Total	168,839	72,871	--	12,708	72,333	147,420	474,171
CORVALLIS ECONOMIC AREA							
Shake and shingle	--	--	--	--	--	--	--
Sawmills[2]							
D	1,476	206	--	425	--	16,257	18,364
C	54,275	19,941	--	1,752	8,718	20,192	104,878
B	33,345	20,116	--	--	7,304	24,295	85,060
A	73,317	39,479	--	4,510	54,402	51,784	223,492
Total	162,413	79,742	--	6,687	70,424	112,528	431,794
Veneer	47,049	34,225	--	4,250	9,785	7,815	103,124
Veneer and plywood[3]	47,278	29,212	--	1,797	168,148	42,899	289,334
Pulp	--	--	--	--	--	--	--
Total	256,740	143,179	--	12,734	248,357	163,242	824,252
EUGENE ECONOMIC AREA							
Shake and shingle	3,600	1,800	--	--	--	3,600	9,000
Sawmills[2]							
D	3,350	6,550	--	--	3,300	9,875	23,075
C	97,891	38,036	--	489	1,700	25,149	163,265
B	113,994	51,524	--	1,200	1,540	51,155	219,413
A	143,856	18,988	--	3,744	294,427	33,650	494,665
Total	359,091	115,098	--	5,433	300,967	119,829	900,418
Veneer	171,108	20,609	--	--	16,425	32,016	240,158
Veneer and plywood[3]	229,132	77,324	--	275	211,326	26,152	544,209
Pulp	--	--	--	--	--	--	--
Total	762,931	214,831	--	5,708	528,718	181,597	1,693,785

See footnotes at end of table

continued

Table 11. — Volume of logs used from each ownership source, by type of plant and economic area, Douglas-fir region, 1966 (continued)
(Thousand board feet, Scribner log rule)

Plant type	National Forest Administration	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private [1]	Total
ROSEBURG ECONOMIC AREA							
Shake and shingle	--	--	--	--	--	--	--
Sawmills[2]							
D	--	1,444	--	614	666	6,028	8,752
C	38,377	14,252	--	--	3,659	28,535	84,823
B	95,546	68,183	--	1,075	48,729	33,719	247,252
A	12,742	31,598	--	--	--	37,260	81,600
Total	146,665	115,477	--	1,689	53,054	105,542	422,427
Veneer	127,083	70,931	--	1,073	37,579	8,700	245,366
Veneer and plywood[3]	67,692	54,940	--	--	83,039	36,235	241,906
Pulp	--	--	--	--	--	--	--
Total	341,440	241,348	--	2,762	173,672	150,477	909,699
COOS BAY ECONOMIC AREA							
Shake and shingle	--	--	--	--	--	--	--
Sawmills[2]							
D	--	633	--	900	--	2,643	4,176
C	1,509	9,100	--	27,167	3,600	4,809	46,185
B	13,588	3,065	--	17,803	71,728	25,018	131,202
A	40,077	36,620	--	20,599	176,247	86,088	359,631
Total	55,174	49,418	--	66,469	251,575	118,558	541,194
Veneer	24,255	10,562	--	1,361	49,258	19,445	104,881
Veneer and plywood[3]	68,827	60,371	--	8,179	234,824	23,898	396,099
Pulp	7,255	3,897	--	3,740	264	47,505	62,661
Total	155,511	124,248	--	79,749	535,921	209,406	1,104,835
MEDFORD ECONOMIC AREA							
Shake and shingle	--	--	--	--	--	--	--
Sawmills[2]							
D	7,600	15,000	--	-	--	10,400	33,000
C	484	10,647	--	-	--	9,468	20,599
B	136,328	63,225	--	--	35,092	43,258	277,903
A	110,775	43,410	--	2,313	21,415	16,954	194,867
Total	255,187	132,282	--	2,313	56,507	80,080	526,369
Veneer	42,277	10,707	--	372	6,490	9,590	69,436
Veneer and plywood[3]	80,225	60,633	--	--	62,470	22,180	225,508
Pulp	--	--	--	--	--	--	--
Total	377,689	203,622	--	2,685	125,467	111,850	821,313

See footnotes at end of table.

continued

Table 11. — Volume of logs used from each ownership source, by type of plant and economic area, Douglas-fir region, 1966 (continued)
(Thousand board feet, Scribner log rule)

Plant type	National Forest Administration	Bureau of Land Management	Bureau of Indian Affairs	State	Company owned	Other private[1]	Total
			EUREKA ECONOMIC AREA				
Shake and shingle	--	--	--	--	--	500	500
Sawmills[2]							
D	--	--	--	--	--	1,500	1,500
C	101,940	8,180	--	--	95,503	82,726	288,349
B	240,966	11,380	10,000	--	137,833	213,400	613,579
A	162,302	1,560	7,000	--	376,146	268,389	815,397
Total	505,208	21,120	17,000	--	609,482	566,015	1,718,825
Veneer	114,274	--	20,437	--	35,577	3,240	173,528
Veneer and plywood[3]	18,502	--	4,637	--	119,126	84,788	227,053
Pulp	--	--	--	--	--	--	--
Total	637,984	21,120	42,074	--	764,185	654,543	2,119,906

[1] *Other private timber consists of purchased timber volumes from forest industry lands or other private landowning classes.*

[2] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

[3] *Integrated operations producing both veneer and plywood.*

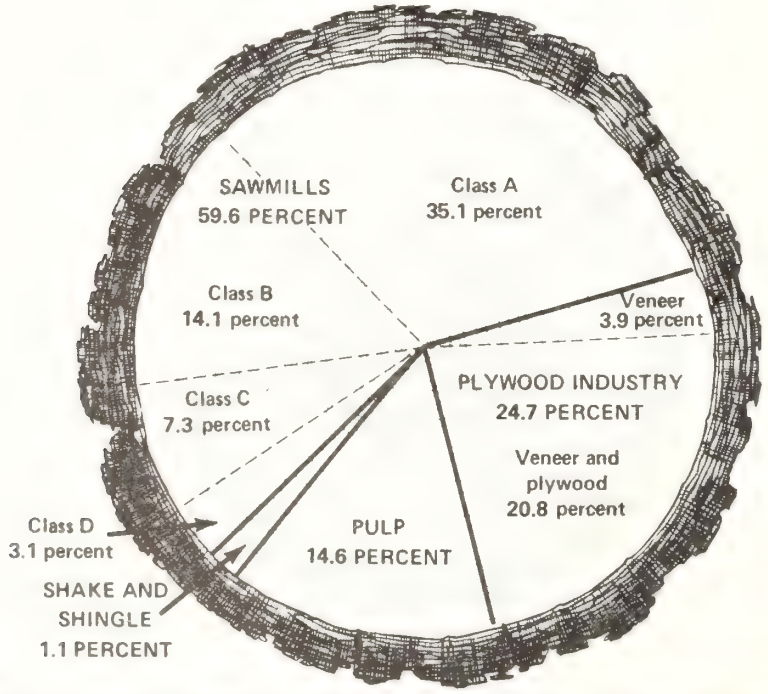
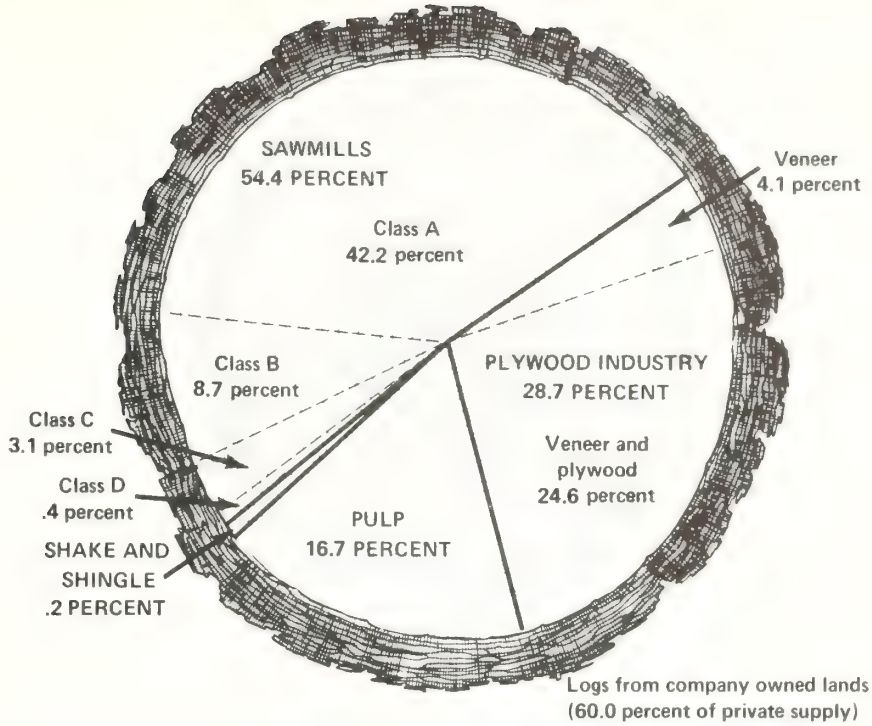


Figure 25. — Use of private timber in domestic production, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.



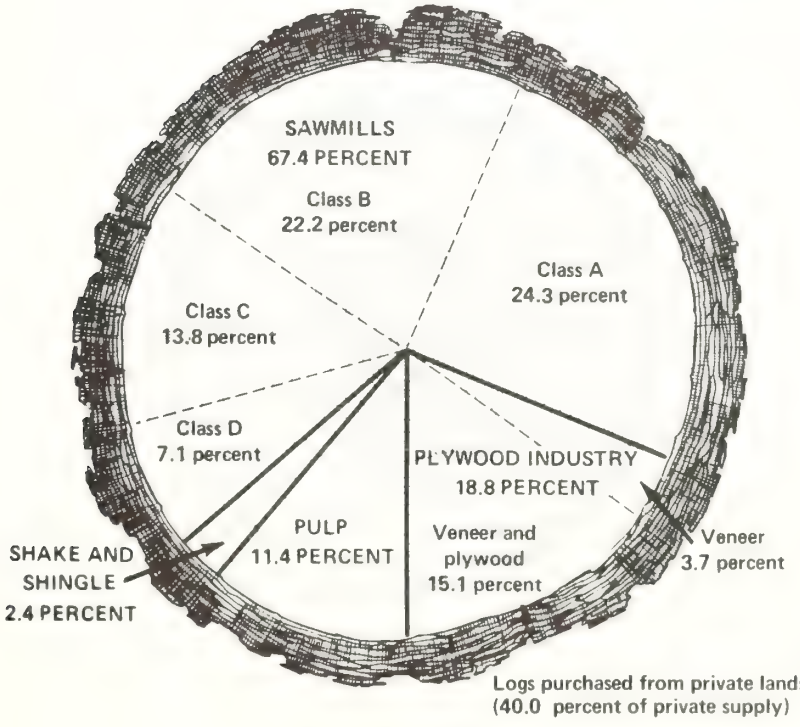


Figure 26. — Use of private logs from company owned lands and purchased logs, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

rated highly dependent on timber-based employment — Astoria, Port Angeles, Longview, and Aberdeen — National Forest logs accounted for less than 17 percent of the logs used. Each of these areas reported consuming less than 100 million board feet of Forest Service logs in 1966. All three of the region's moderately timber-dependent areas, Tacoma, Portland, and Bellingham, reported obtaining over 40 percent of their logs from National Forests.

The region's lumber industry consumed the largest volume of Forest Service logs, accounting for 2,518 million board feet or 47.7 percent of the total, followed by the plywood industry, 36.8 percent, and pulp plants, 5.1 percent (fig. 27). In a study using 1960 data, National Forest log distribution among primary processing facilities was found to be very similar to that obtained here: 61 percent to sawmills, 31 percent to veneer operations, 5 percent to pulp plants, 2 percent to shake and shingle plants, and 1 percent as log exports.[13] Log export volumes are not included in this study because reported volumes are volumes consumed by domestic mills. The major change according to these figures is an increased proportion of National Forest logs being consumed by veneer producers in 1966 and a decreased proportion going to sawmills.

Bureau of Land Management lands contribute 8.1 percent of logs used

The Bureau of Land Management (BLM), with 7.4 percent of the region's commercial forest land area, supplied 1,109 million board feet of logs, or 8.1 percent of the total logs used by the region's forest industry in 1966. BLM logs were used chiefly by areas in southwest Oregon, where the BLM lands are concentrated. Heaviest consumption was in the Roseburg area, where the forest industry used 241 million board feet, or 21.8 percent of total BLM logs consumed in the region. This area also obtained a larger portion of its log supply from BLM than did any other area, 26.5 percent. Eugene and Medford were other major consumers of BLM timber.

The plywood industry derived a larger portion of logs from the Bureau than from any other ownership, accounting for 44.7 percent of all BLM timber; sawmills consumed 54.0 percent of the Bureau's supply and pulp plants, 1.1 percent (fig. 28).

Indian lands supplied less than 1 percent of logs consumed in region

Lands managed by the Bureau of Indian Affairs (BIA) contributed 111 million board feet of timber in 1966, 0.8 percent of the total volume of logs consumed in the region. Indian lands, like those managed by BLM, are geographically concentrated with the largest block holdings located on the Quinault Indian Reservation in the Aberdeen economic area and the Hoopa Valley Indian Reservation in the Eureka economic area. These two areas were the largest consumers of Indian timber. The region's pulp operations were the major consumers of BIA timber, accounting for 31.0 percent of the total (fig. 29).

State-owned logs account for 4.2 percent of logs used in region

The region's forest industries used 569.8 million board feet of State-owned timber, 4.2 percent of the region's total timber consumption in 1966. Sawmills used 51.8 percent of State-supplied logs; the plywood industry, 26.2 percent; and pulp plants, 20.4 percent (fig. 30).

The Tacoma area in Washington and the Coos Bay area in Oregon were the major consumers of State timber. No logs from State lands were reported consumed by the forest industry in the Eureka area of northern California. State logs were most important to the Port Angeles forest industry, where they represented 18.7 percent of all logs used.

[13] *Mead, Walter J. Log flow and use from Region 6 National Forests. 20 pp., illus. 1963 (unpublished manuscript on file at the Pacific Northwest Forest & Range Exp. Sta., Portland, Oreg.).*

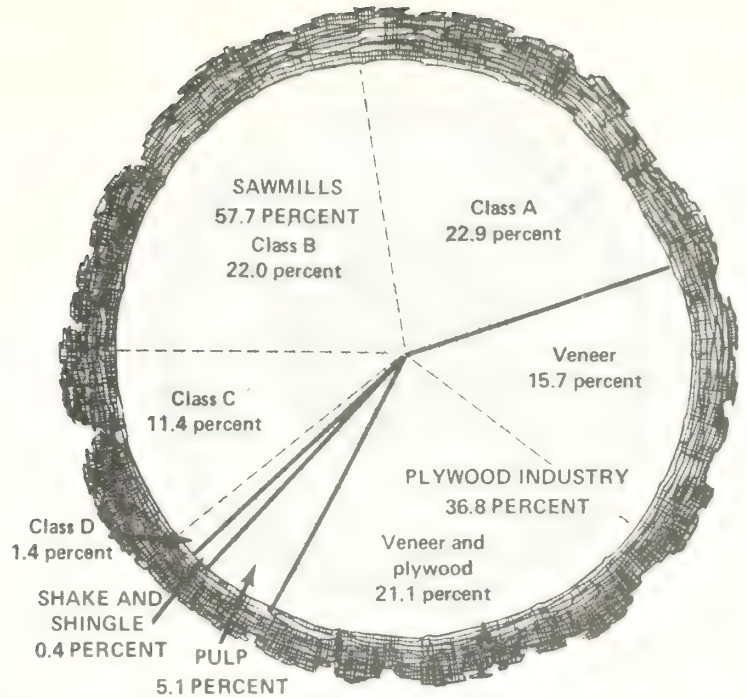


Figure 27. — Use of National Forest timber in domestic production, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

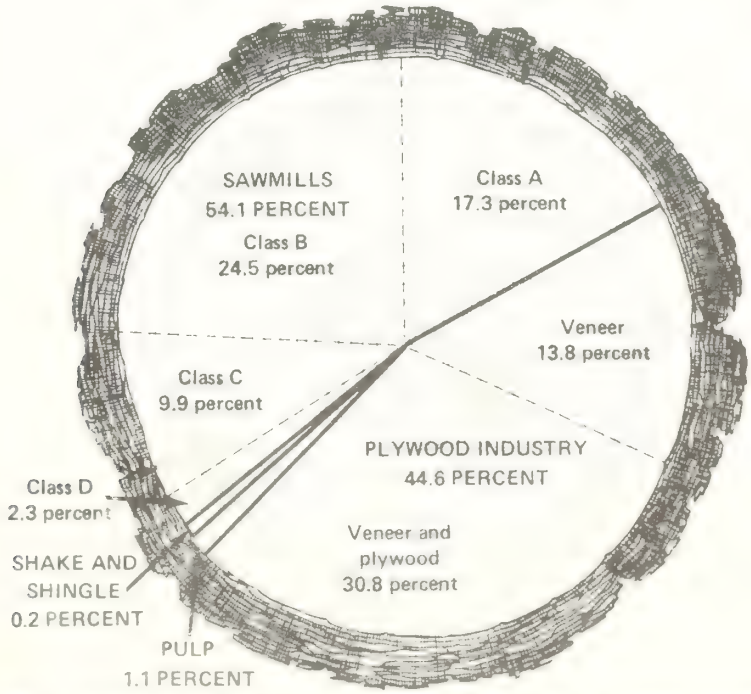


Figure 28. — Use of Bureau of Land Management timber in domestic production, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

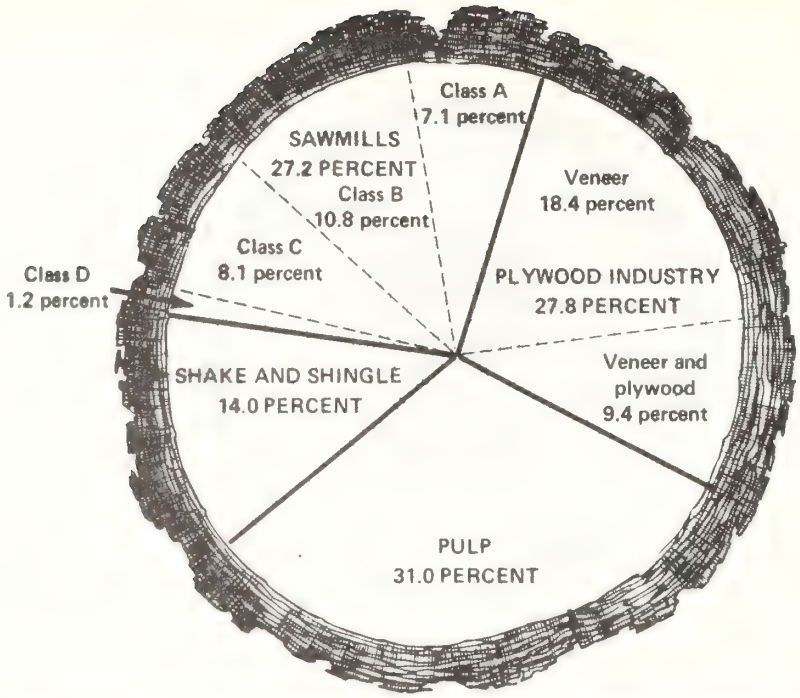


Figure 29. — Use of Bureau of Indian Affairs timber in domestic production, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

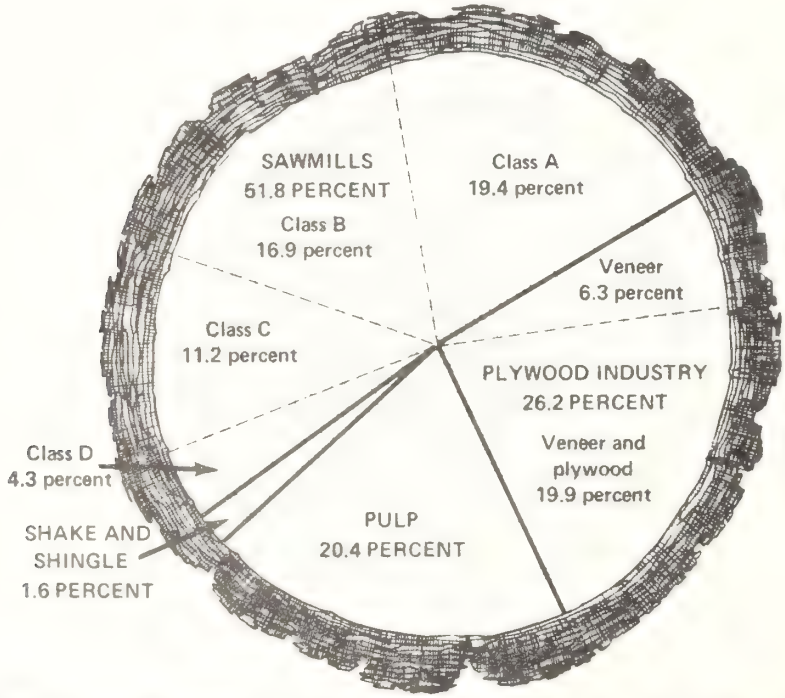


Figure 30. — Use of State timber in domestic production, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

SUPPLY SOURCES FOR THE REGION'S FOREST INDUSTRIES

Sawmill industry obtains over half its timber supply from private lands

The sawmill industry obtained 56.7 percent of its logs from private lands in 1966, 31.1 percent from company lands, and 25.6 percent from other private sources, (fig. 31). The National Forests supplied 31.7 percent of the industry's logs, Bureau of Land Management furnished 7.5 percent, and Indian lands 0.4 percent, for a total of 39.6 percent from Federal lands. In a survey by the Western Wood Product Association's Market Research Department in 1965 covering 90 percent of the western production of 1964, sawmills in western Oregon and western Washington reported obtaining 41.9 percent of their timber from Federal lands and 32.0 percent from company-owned lands.[14]

[14] *Western Wood Products Association. Profile of western sawmills. 13 pp. Portland, Oreg. 1966.*

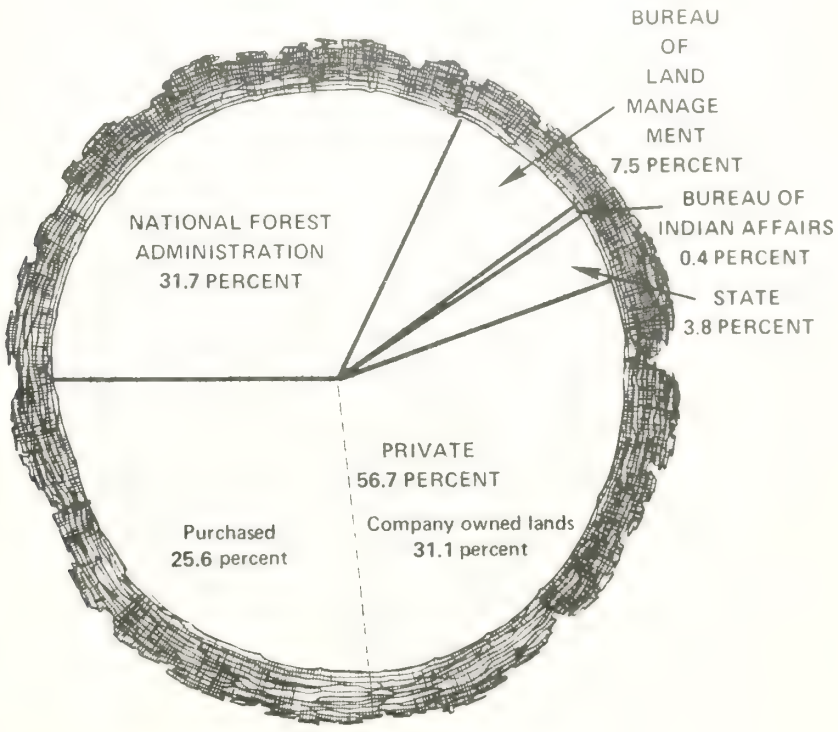

BUREAU OF LAND MANAGEMENT 7.5 PERCENT
BUREAU OF INDIAN AFFAIRS 0.4 PERCENT
STATE 3.8 PERCENT
NATIONAL FOREST ADMINISTRATION 31.7 PERCENT
PRIVATE 56.7 PERCENT
Purchased 25.6 percent
Company owned lands 31.1 percent

Figure 31. — Source of timber supply for sawmills, Douglas-fir region, 1966.

A 1969 report by the same association shows Federal lands providing sawmills with 39.6 percent of their timber and company owned lands, 34.0 percent in 1968.[15] This last report represented about 85 percent of the region's lumber production capacity.

Private supply was the source for more than 50 percent of the log requirements for sawmills in seven of the region's 15 areas. Consumption of logs by plant type for each economic area is given in table 11. Bellingham and Tacoma were the only areas in Washington that obtained less than 50 percent of their saw logs from private lands, and Astoria, Coos Bay, and Eureka were the only areas outside Washington receiving 50 percent or more of their saw logs from this source.

The Longview area sawmill industry's log supply contained the greatest portion of private logs, over 80 percent, and the Medford area had the smallest portion, about 25 percent.

Sawmill classes B and C relied more heavily on Forest Service and Bureau of Land Management stumpage than did the small class D and the large class A sawmills (fig. 32). Also, although private timber furnished almost half the supply for all sawmill classes, the proportion of purchased private timber to the total increased as mill size decreased. Smaller sawmills do not as a rule have extensive land holdings from which to supply their operations and consequently rely on purchased logs. Private timber is more often sought by these smaller operations because many of the public sales are too large or contain road construction requirements not manageable by the small firm.

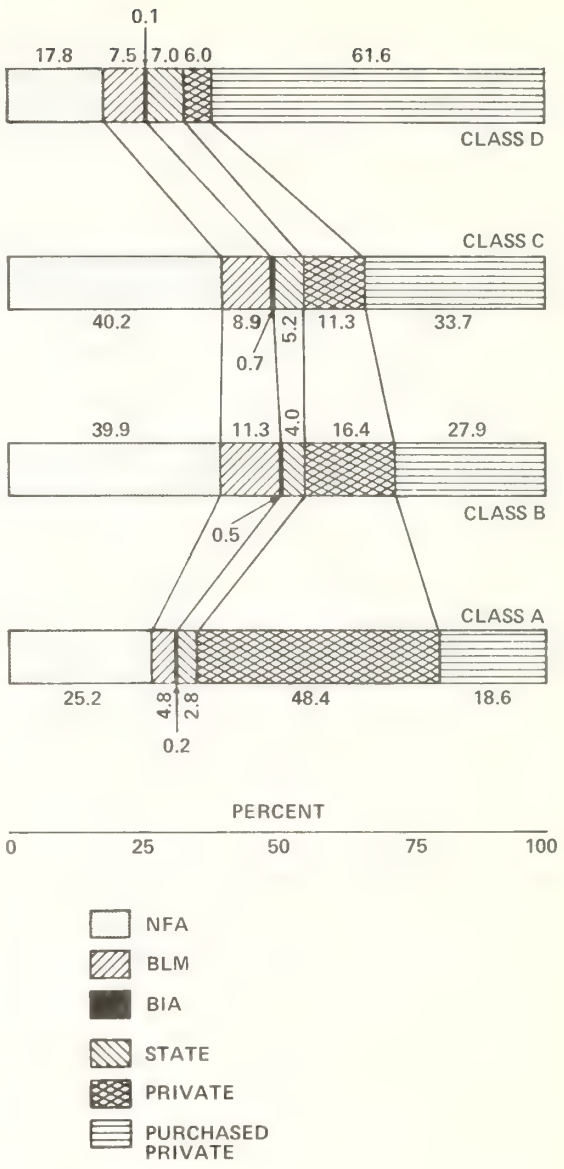


Figure 32. — Percent of logs used from each ownership class by sawmill class, Douglas-fir region, 1966. Class A sawmills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.

Federal lands furnish over half of plywood industry's logs

The plywood industry obtained 51.4 percent of its 1966 veneer log supply from Federal lands, 38.6 percent from National Forest lands, 12.0 percent from Bureau of Land Management lands, and 0.8 percent from In-

[15] *Western Wood Products Association. 1968 statistical supplement to facts. 27 pp. Portland, Oreg. 1969.*

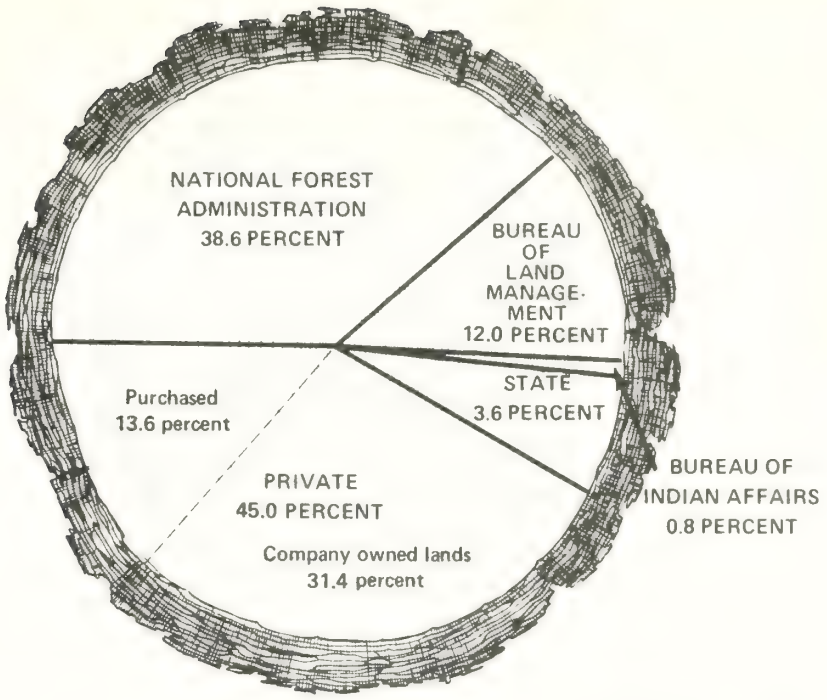


Figure 33. — Source of timber supply for the plywood industry, Douglas-fir region, 1966.

dian lands. Private sources furnished 45.0 percent of the industry's logs, 31.4 percent from the mills' own lands (fig. 33).

Veneer plants obtained a much larger portion, over 70 percent, of their log supply from Federal lands than did the integrated veneer and plywood operations which produce both veneer and plywood (fig. 34). The integrated operations, which obtained only 43 percent from Federal lands and over 53 percent from private lands, tend to be the larger, landowning companies. This accounts for the difference in portions of timber coming from company owned lands: 16 percent for veneer plants versus 38 percent for the integrated plants.

Pulp plants obtain 74 percent of roundwood from private lands

The pulp industry obtained 50.9 percent of its roundwood needs from its own lands and another 23.2 percent from other private sources, for a total from private lands of 74.1 percent or 1,102 million board feet (fig. 35). Federal timber accounted for only 18.1 percent of the total and State lands, 7.8 percent. Because of the geographical location of BLM lands away from the pulp-making centers in the region, only 0.8 percent of the industry's logs came from this source. Of the eight economic areas reporting log consumption by pulp plants, six of the areas obtained over 70.0 percent of their pulp log requirements from private lands.

Shake and shingle plants rely heavily on private timber

Shake and shingle plants used private logs for 66 percent of their timber requirements, but only 9 percent came from land owned by these firms. National Forests furnished 13.0 percent of these plants' timber requirements, and the Bureau of Indian Affairs furnished 12.1 percent.

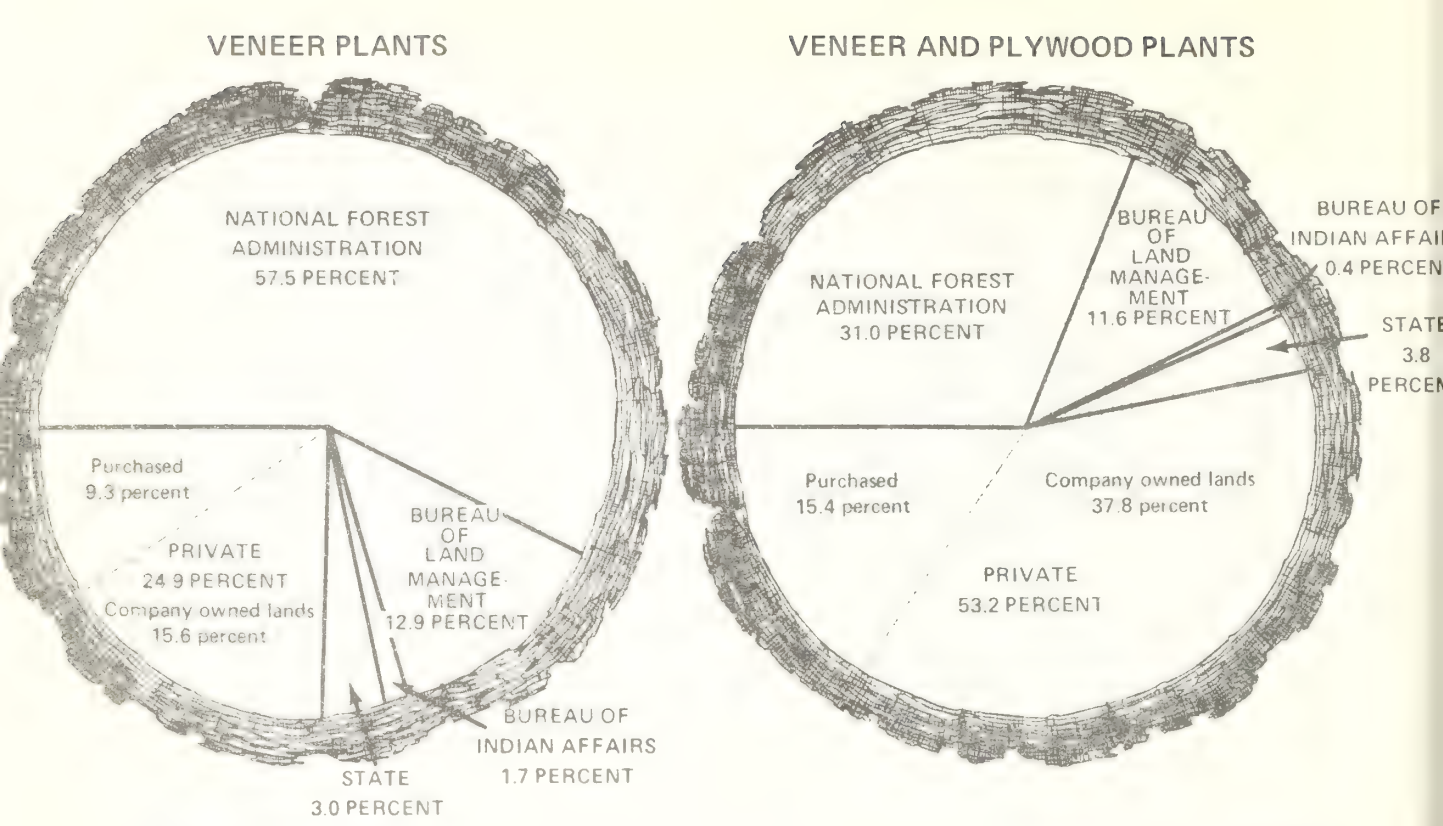

VENEER PLANTS
NATIONAL FOREST ADMINISTRATION 57.5 PERCENT
Purchased 9.3 percent
PRIVATE 24.9 PERCENT
Company owned lands 15.6 percent
BUREAU OF LAND MANAGE-MENT 12.9 PERCENT
BUREAU OF INDIAN AFFAIRS 1.7 PERCENT
STATE 3.0 PERCENT
VENEER AND PLYWOOD PLANTS
NATIONAL FOREST ADMINISTRATION 31.0 PERCENT
BUREAU OF LAND MANAGE-MENT 11.6 PERCENT
BUREAU OF INDIAN AFFAI 0.4 PERCEN
STATE 3.8 PERCEN
Purchased 15.4 percent
Company owned lands 37.8 percent
PRIVATE 53.2 PERCENT

Figure 34. — Source of timber supply for veneer and veneer and plywood plants, Douglas-fir region, 1966.

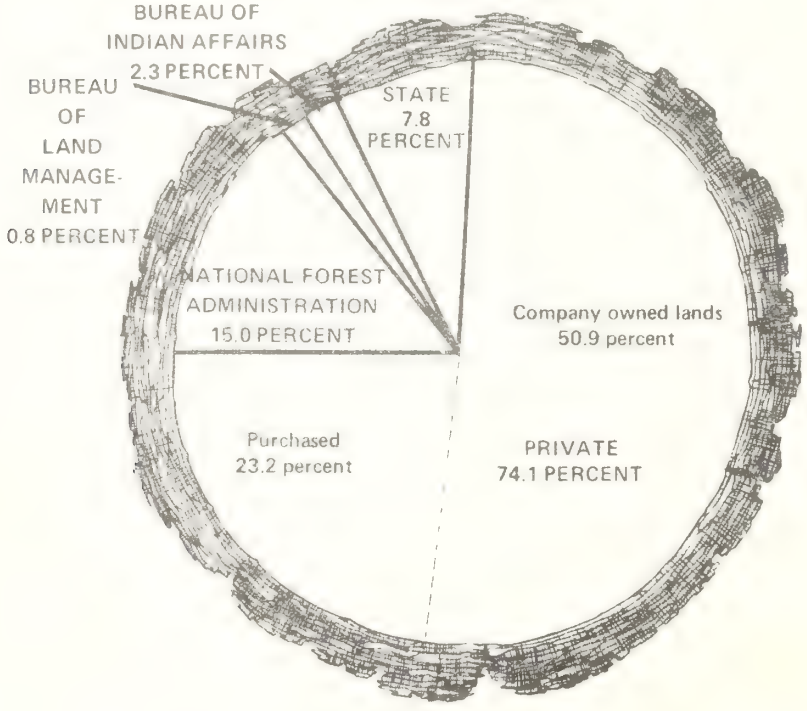

BUREAU OF INDIAN AFFAIRS 2.3 PERCENT
BUREAU OF LAND MANAGE-MENT 0.8 PERCENT
STATE 7.8 PERCENT
NATIONAL FOREST ADMINISTRATION 15.0 PERCENT
Company owned lands 50.9 percent
Purchased 23.2 percent
PRIVATE 74.1 PERCENT

Figure 35. — Source of timber supply for pulpmills, Douglas-fir region, 1966.

NATIONAL FOREST LOG MARKETS

The National Forest System furnishes almost a third of the timber supply used by the region's forest industry, and in many areas National Forest logs are the backbone of the forest industry. Because of the importance of the National Forests to the region's timber economy, the markets for each of the region's National Forests are discussed below.

Each National Forest in the region has a certain geographical market for its logs. This market is largely determined by the Forests' proximity to good road or water transportation systems and timber composition. The Forests are considered in order of their contributions to the region's timber supply.

The Willamette National Forest supplied a larger volume of logs to the region's forest industry than any other single Forest in 1966, 890.6 million board feet, or 20.4 percent of all Forest Service logs used (table 12, fig. 36). The Willamette Valley was the Forest's major market with the Eugene area consuming 588.3 million board feet, or 66 percent of the total. The Corvallis and Salem areas were also important markets for the Willamette timber with a small amount going to the Portland and Tacoma areas.

In total, 50.7 percent of the Willamette timber volume was utilized by the plywood industry and 49.0 percent by the lumber industry; shake and shingle mills accounted for the remainder. The Willamette National Forest furnished integrated veneer and plywood operations almost 2½ times as much timber and sawmills over twice as much timber as any other National Forest in the region. No Willamette National Forest logs were reported as used directly by the pulp industry in 1966.

The Gifford Pinchot National Forest supplied 467.3 million board feet of logs to the region's forest industry in 1966, 10.7 percent of total National Forest volume used in the region. The Forest is the region's second largest supplier of National Forest logs and has one of the widest market areas in the region; however, its main markets lie in the geographic area between Tacoma and Portland. The Portland economic area alone accounted for 232.3 million board feet, or about half the volume supplied by the Gifford Pinchot in 1966. The Tacoma area was the second largest market for the Forest's logs, followed by the Longview, Seattle, and Astoria areas.

Lumber mills used 57 percent, plywood plants 39 percent, and pulp plants 4 percent of the Forest's logs. The Gifford Pinchot National Forest supplied the small class D sawmills with almost twice as much timber as any other National Forest in the region.

The Umpqua National Forest was the region's third largest supplier of National Forest logs in 1966, 453.1 million board feet or 10.4 percent of the total. The areas of Roseburg, Medford, and Eugene are the major markets for the Forest's logs with the Roseburg area using 341.4 million board feet or over 75 percent of the total. The lumber industry, mainly Roseburg's class B sawmills, used 45 percent of the Forest's logs, veneer mills used 31 percent, and integrated plywood plants 24 percent. No Umpqua National Forest logs were reported as used directly by pulpmills.

The Siuslaw National Forest supplied the region's forest industry with 342.2 million board feet of logs in 1966, 7.8 percent of the total from Forest Service lands. The markets for this Forest's timber stretch from Portland and Astoria to Coos Bay, covering all of western Oregon except the southwest corner of the State. The economic areas of Eugene and Corvallis were the Forest's major log markets, using 120.7 and 97.1 million board feet, respectively. The lumber industry was the Forest's major log buyer, using 68.1 percent of the total volume.

The Mount Hood National Forest supplied 320.9 million board feet of timber to its market, mainly the lower Willamette Valley. The Portland area's forest industry used 305.5 million board feet of the Forest's logs, over 95 percent of the total. Over 77 percent of the Forest's logs went to the region's lumber industry.

The Olympic National Forest supplied the forest industry in northwest Washington with

Table 12. — Use of National Forest logs in the Douglas-fir region, by economic area and type of plant, 1966
(Thousand board feet, Scribner log rule)

National Forest of log origin and economic area of utilization	Type of plant									
	Shake and shingle	Sawmills[1]					Veneer	Veneer and plywood[2]	Pulp	Total
		D	C	B	A	Total				
DESCHUTES NATIONAL FOREST										
Portland	--	--	--	--	--	--	--	1,600	--	1,600
FREMONT NATIONAL FOREST										
Eugene	--	--	--	--	--	--	1,800	--	--	1,800
GIFFORD PINCHOT NATIONAL FOREST										
Seattle	--	--	--	--	--	--	--	12,059	--	12,059
Tacoma	124	350	55,537	5,770	29,700	91,357	43,420	23,410	4,000	162,311
Longview	41	6,960	12,000	10,472	14,088	43,520	--	6,491	2,731	52,783
Astoria	--	--	--	--	--	--	--	7,820	--	7,820
Portland	13	15,587	2,990	18,481	94,322	131,380	24,058	64,508	12,375	232,334
Total Gifford Pinchot	178	22,897	70,527	34,723	138,110	266,257	67,478	114,288	19,106	467,307
KLAMATH NATIONAL FOREST										
Medford	--	2,800	--	12,100	8,564	23,464	2,828	--	--	26,292
Eureka	--	--	7,650	133,443	37,629	178,722	44,167	4,691	--	227,580
Total Klamath	--	2,800	7,650	145,543	46,193	202,186	46,995	4,691	--	253,872
MOUNT BAKER NATIONAL FOREST										
Seattle	2,625	4,200	14,977	55,000	7,200	81,377	--	8,400	50,560	142,962
Bellingham	4,535	2,850	13,678	--	--	16,528	--	28,429	49,467	98,959
Port Angeles	--	--	--	--	--	--	--	795	--	795
Tacoma	--	--	--	--	2,627	2,627	--	845	--	3,472
Total Mount Baker	7,160	7,050	28,655	55,000	9,827	100,532	--	38,469	100,027	246,188
MOUNT HOOD NATIONAL FOREST										
Astoria	--	--	--	--	--	--	--	5,213	--	5,213
Portland	--	12,272	52,397	59,510	116,125	240,304	17,160	41,277	6,800	305,541
Salem	--	--	--	7,373	--	7,373	2,130	--	--	9,503
Corvallis	--	--	--	--	--	--	--	599	--	599
Total Mount Hood	--	12,272	52,397	66,883	116,125	247,677	19,290	47,089	6,800	320,856

See footnotes at end of table, p. 64.

Table 12. — Use of National Forest logs in the Douglas-fir region, by economic area and type of plant, 1966 (continued)
(Thousand board feet, Scribner log rule)

National Forest of log origin and economic area of utilization	Type of plant									
	Shake and shingle	Sawmills[1]					Veneer	Veneer and plywood[2]	Pulp	Total
		D	C	B	A	Total				
OKANOGAN NATIONAL FOREST										
Seattle	--	--	--	--	1,350	1,350	--	--	--	1,350
OLYMPIC NATIONAL FOREST										
Seattle	--	--	4,970	--	13,500	18,470	--	8,397	--	26,867
Bellingham	--	--	--	--	--	--	--	8,000	--	8,000
Port Angeles	1,363	90	--	--	12,000	12,090	--	15,105	21,439	49,997
Tacoma	--	--	--	1,580	76,357	77,937	32,500	--	3,971	114,408
Aberdeen	3,374	500	--	5,400	52,250	58,150	--	24,970	11,213	97,707
Total Olympic	4,737	590	4,970	6,980	154,107	166,647	32,500	56,472	36,623	296,979
ROGUE RIVER NATIONAL FOREST										
Medford	--	--	242	106,199	13,954	120,395	31,539	53,517	--	205,451
SHASTA-TRINITY NATIONAL FOREST										
Eureka	--	--	68,135	66,449	53,553	188,137	7,320	2,007	--	197,464
SISKIYOU NATIONAL FOREST										
Portland	--	--	--	--	--	--	--	3,200	--	3,200
Coos Bay	--	--	--	13,588	35,499	49,087	24,255	68,299	5,649	147,290
Medford	--	600	242	4,579	47,852	53,273	--	11,750	--	65,023
Eureka	--	--	--	--	--	--	1,873	2,063	--	3,936
Total Siskiyou	--	600	242	18,167	83,351	102,360	26,128	85,312	5,649	219,449
SIUSLAW NATIONAL FOREST										
Astoria	--	--	--	1,844	5,143	6,987	--	12,452	--	19,439
Portland	--	--	16,608	30,323	--	46,931	2,460	12,054	--	61,445
Salem	--	--	--	22,417	5,650	28,067	--	7,168	--	35,235
Corvallis	--	1,102	35,371	17,345	28,729	82,547	14,600	--	--	97,147
Eugene	1,350	--	6,713	32,780	22,776	62,269	34,901	22,171	--	120,691
Coos Bay	--	--	1,509	--	4,578	6,087	--	528	1,606	8,221
Total Siuslaw	1,350	1,102	60,201	104,709	66,876	232,888	51,961	54,373	1,606	342,178
SIX RIVERS NATIONAL FOREST										
Medford	--	--	--	--	800	800	--	--	--	800
Eureka	--	--	26,155	41,074	71,120	138,349	60,914	9,741	--	209,004
Total Six Rivers	--	--	26,155	41,074	71,920	139,149	60,914	9,741	--	209,804

See footnotes at end of table, p. 64

Table 12. — Use of National Forest logs in the Douglas-fir region, by economic area and type of plant, 1966 (continued)
(Thousand board feet, Scribner log rule)

National Forest of log origin and economic area of utilization	Type of plant									
	Shake and shingle	Sawmills[1]					Veneer	Veneer and plywood[2]	Pulp	Total
		D	C	B	A	Total				
SNOQUALMIE NATIONAL FOREST										
Seattle	600	1,695	11,257	16,400	12,990	42,342	--	17,990	19,716	80,648
Bellingham	--	--	--	--	--	--	--	10,000	10,696	20,696
Tacoma	234	--	14,064	13,600	7,360	35,024	21,880	34,348	23,220	114,706
Total Snoqualmie	834	1,695	25,321	30,000	20,350	77,366	21,880	62,338	53,632	216,050
UMPQUA NATIONAL FOREST										
Portland	--	--	--	--	--	--	--	1,600	--	1,600
Eugene	--	--	10,429	8,982	--	19,411	8,568	24,186	--	52,165
Roseburg	--	--	38,377	95,546	12,742	146,665	127,083	67,692	--	341,440
Medford	--	--	--	550	38,466	39,016	5,012	13,858	--	57,886
Total Umpqua	--	--	48,806	105,078	51,208	205,092	140,663	107,336	--	453,091
WENATCHEE NATIONAL FOREST										
Seattle	150	4,933	1,200	3,600	3,650	13,383	--	370	--	13,903
WILLAMETTE NATIONAL FOREST										
Tacoma	--	--	--	--	--	--	--	9,000	--	9,000
Portland	--	--	--	--	2,250	2,250	--	8,000	--	10,250
Salem	--	--	3,000	74,196	--	77,196	13,631	33,274	--	124,101
Corvallis	--	374	18,904	16,000	44,588	79,866	32,449	46,679	--	158,994
Eugene	2,250	3,350	80,749	72,232	121,080	277,411	125,839	182,775	--	588,275
Total Willamette	2,250	3,724	102,653	162,428	167,918	436,723	171,919	279,728	--	890,620
WINEMA NATIONAL FOREST										
Medford	--	4,200	--	12,900	1,139	18,239	2,898	1,100	--	22,237
TOTAL, ALL FORESTS	16,659	61,863	497,154	959,733	999,631	2,518,381	683,285	918,431	223,443	4,360,199

[1] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift, B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

[2] *Integrated operations producing both veneer and plywood.*

297.0 million board feet of logs. The Tacoma and Aberdeen economic areas were the Forest's main markets with small volumes also going to the Port Angeles, Seattle, and Bellingham areas.

The lumber industry used 56 percent, the plywood industry 30 percent, and the pulp industry 12 percent of the Forest's logs. Shake and shingle plants made up the remaining 2 percent.

Class A mills accounted for over 90 percent of the logs used by the lumber industry.

The **Klamath National Forest** supplied 253.9 million board feet, mainly to the Eureka economic area. The Medford forest industry also used some of the Forest's logs. Sawmills, mainly the class B mills in the Eureka area, used 202.2 million board feet or 79.6 percent of the total.

The **Mount Baker National Forest** in northwest Washington furnished 246.2 million board feet to the region's forest industry. The Puget Sound portion of the region was the Forest's major market, with the Seattle economic area accounting for 58.1 percent of the total, Bellingham 40.2 percent, and Tacoma and Port Angeles the remainder. The Mount Baker National Forest supplied 100.0 million board feet, or 40.6 percent of its total volume, to the pulp industry. This is almost twice as much as any other Forest in the region furnished to pulp operations.

The **Siskiyou National Forest** supplied 219.4 million board feet of logs mainly to the areas in southwest Oregon. A few of the Forest's logs found their way north to the Portland economic area.

The areas around the lower Puget Sound were supplied 216.0 million board feet from the **Snoqualmie National Forest** with the Tacoma area forest industry consuming over half of this volume. Eureka received 209.0 million board feet of the 209.8 million board feet supplied by the **Six Rivers National Forest,** used mainly in lumber production. The **Rogue River National Forest** supplied 205.4 million board feet, all to the Medford economic area, and the **Shasta-Trinity National Forest** supplied the forest industry in the Eureka area with 197.5 million board feet of timber. The **Winema, Wenatchee, Fremont, Deschutes,** and **Okanogan National Forests,** located in eastern Oregon and eastern Washington, also supplied small volumes of timber.

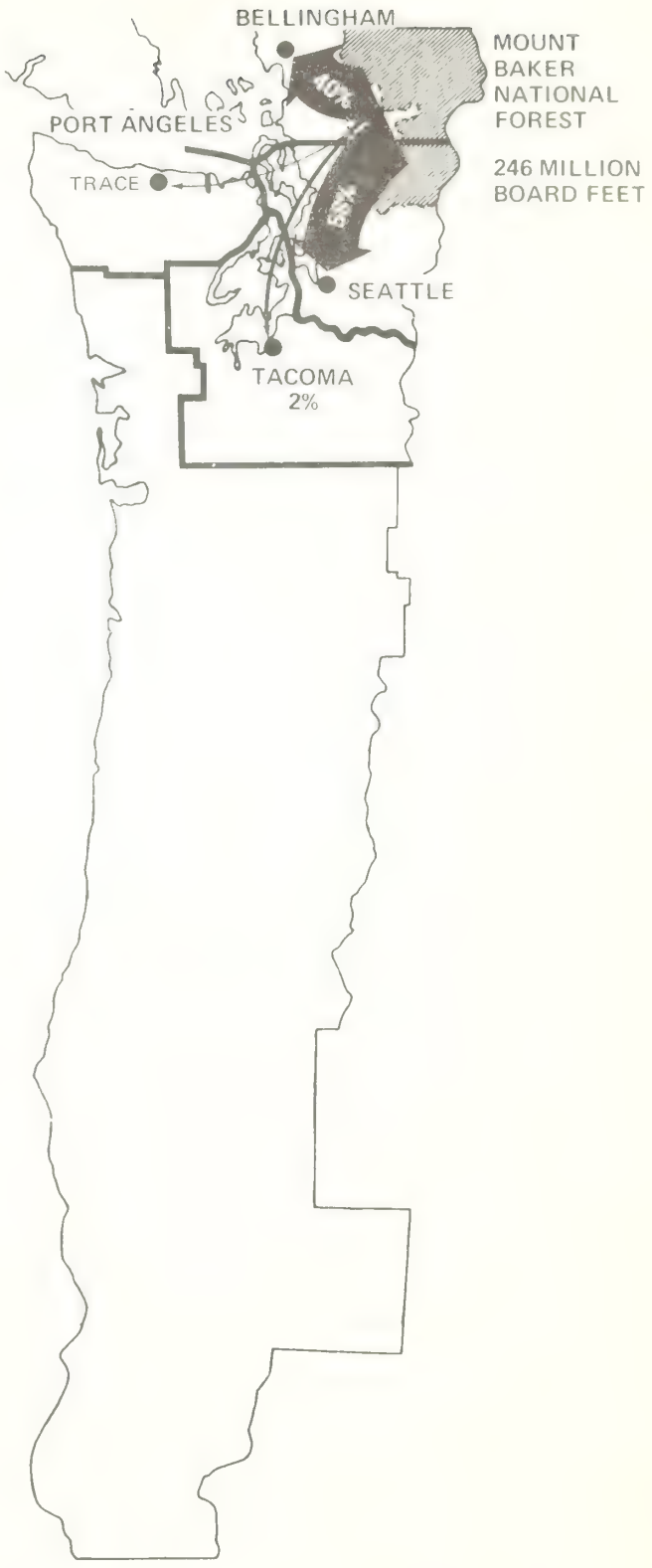
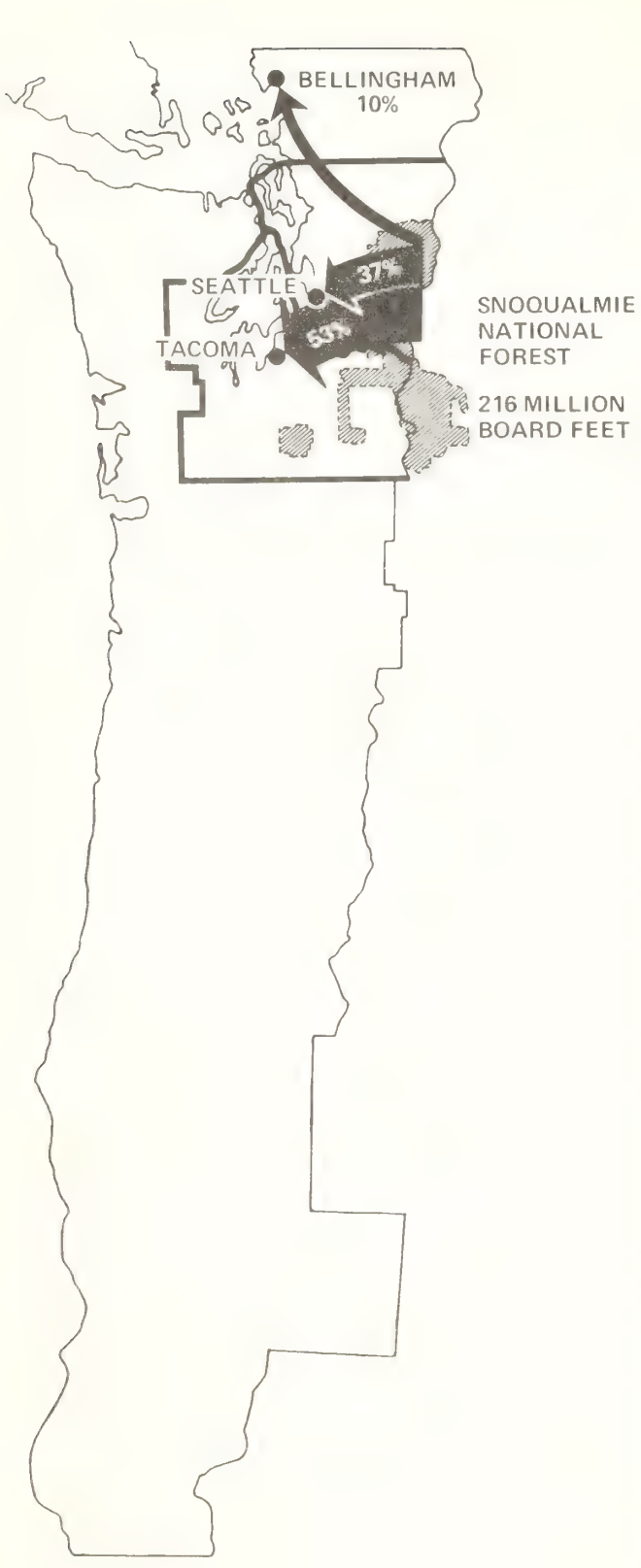
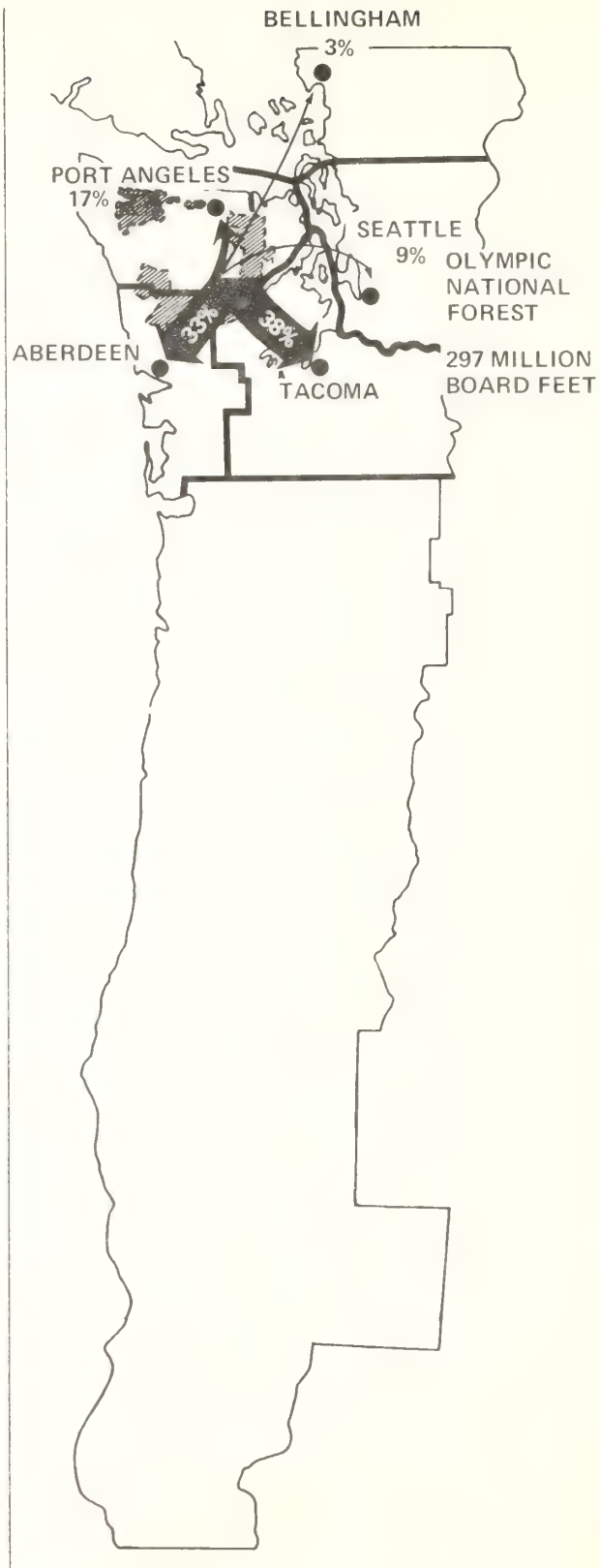
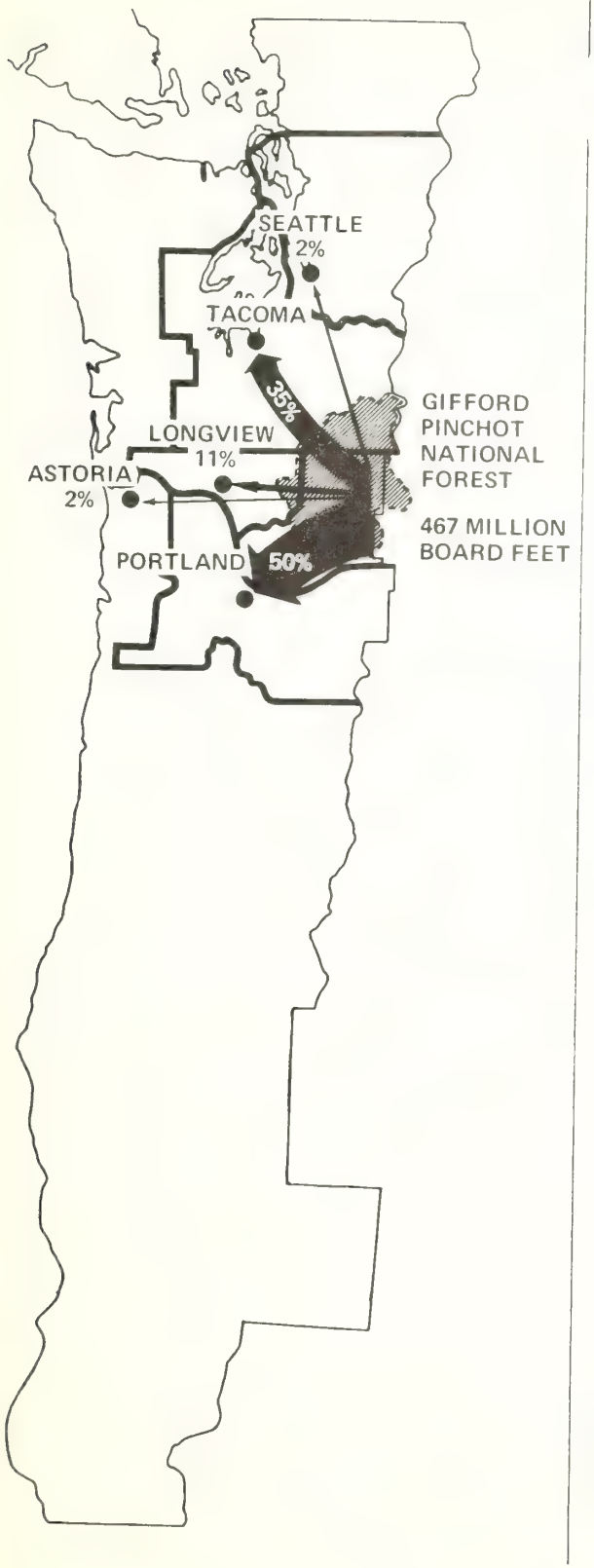
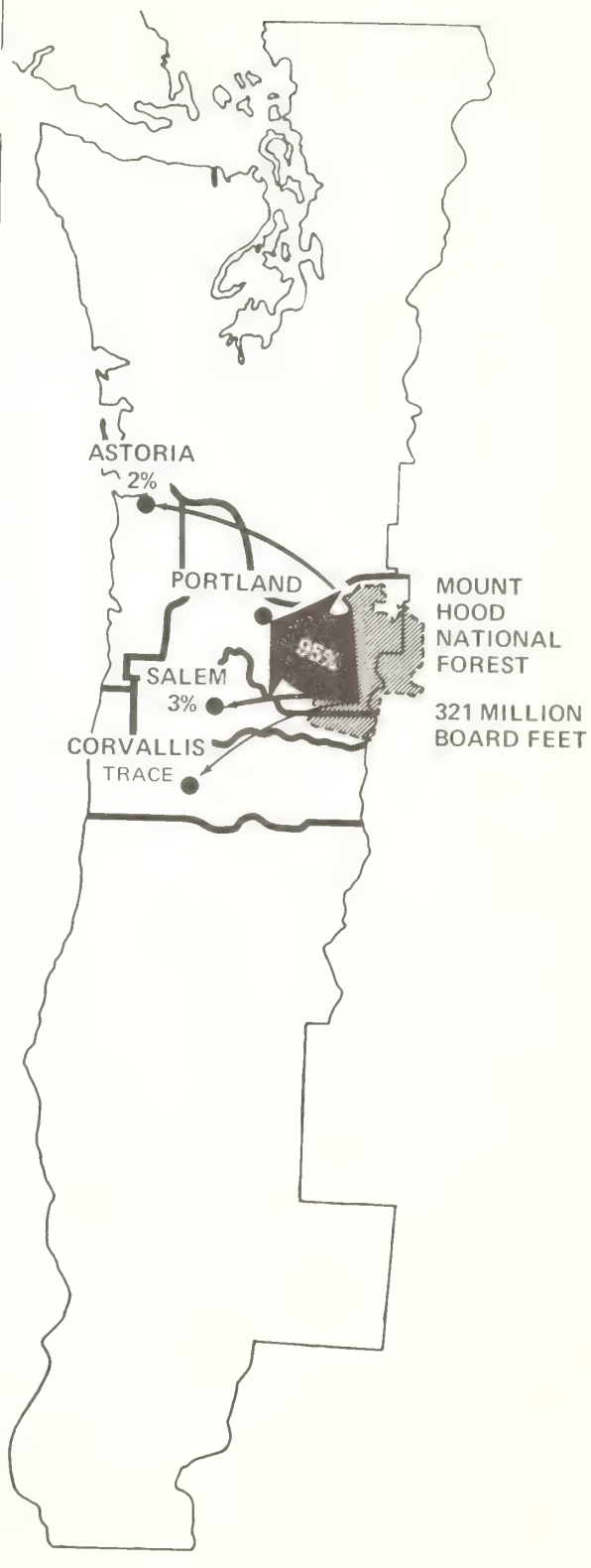


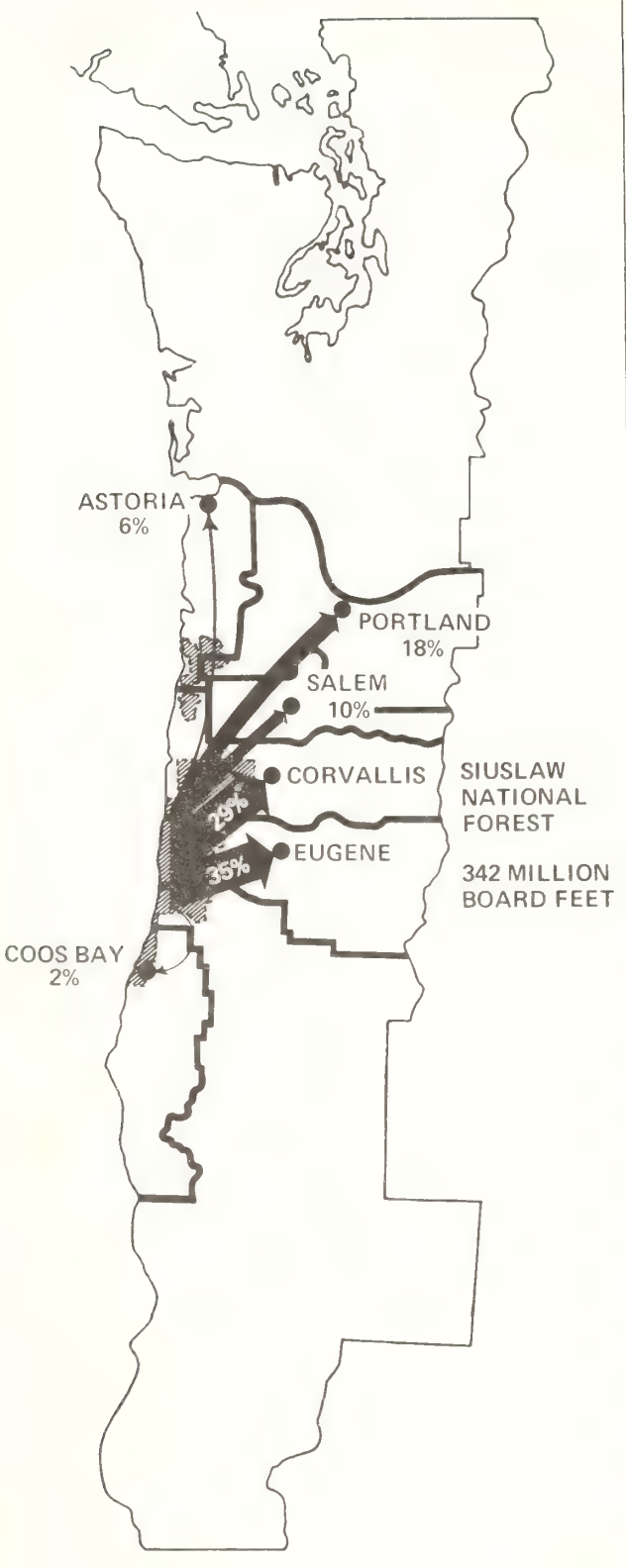
Figure 36. — Log flows to economic areas by National Forest origin, Douglas-fir region, 1966.

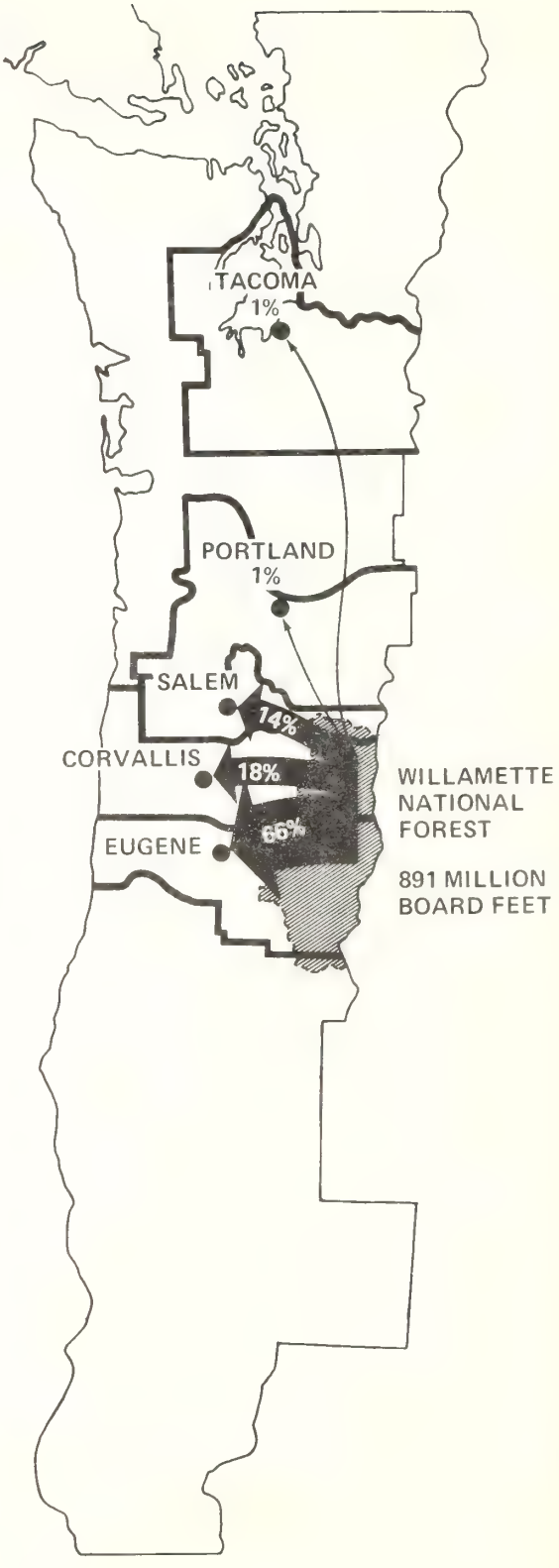

BELLINGHAM
10%
SEATTLE
37%
TACOMA
53%
SNOQUALMIE
NATIONAL
FOREST
216 MILLION
BOARD FEET


BELLINGHAM
3%
PORT ANGELES
17%
SEATTLE
9%
OLYMPIC
NATIONAL
FOREST
ABERDEEN
33%
38%
TACOMA
297 MILLION
BOARD FEET


SEATTLE
2%
TACOMA
35%
LONGVIEW
11%
ASTORIA
2%
PORTLAND
50%
GIFFORD
PINCHOT
NATIONAL
FOREST
467 MILLION
BOARD FEET


ASTORIA
2%
PORTLAND
95%
SALEM
3%
CORVALLIS
TRACE
MOUNT
HOOD
NATIONAL
FOREST
321 MILLION
BOARD FEET


ASTORIA
6%
PORTLAND
18%
SALEM
10%
CORVALLIS
29%
35%
EUGENE
SIUSLAW
NATIONAL
FOREST
342 MILLION
BOARD FEET
COOS BAY
2%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PORTLAND
1%
SALEM
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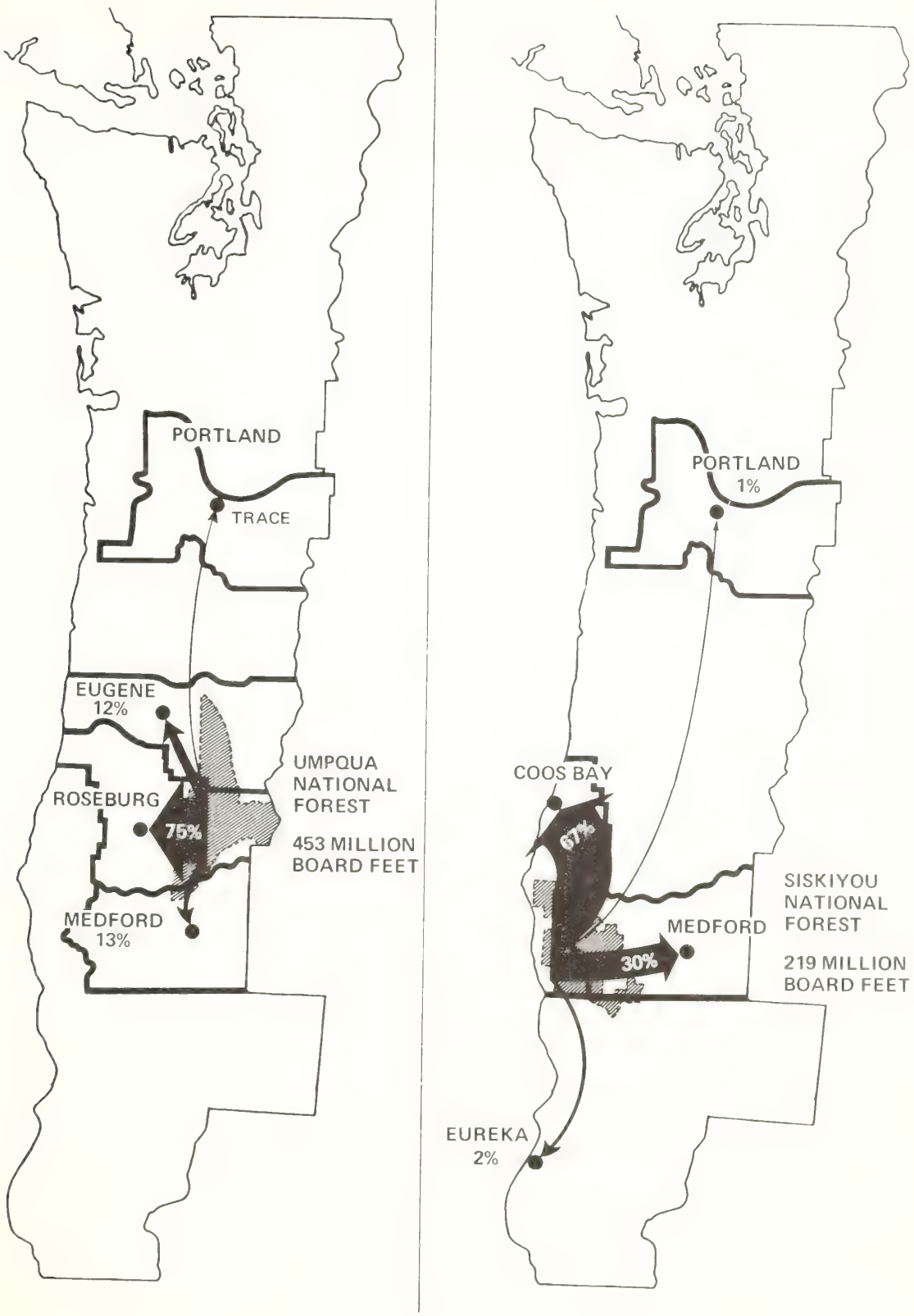
CORVALLIS
18%
66%
EUGENE
WILLAMETTE
NATIONAL
FOREST
891 MILLION
BOARD FEET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EUGENE
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ROSEBURG
75%
UMPQUA
NATIONAL
FOREST
453 MILLION
BOARD FEET
MEDFORD
13%
PORTLAND
1%
COOS BAY
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MEDFORD
30%
SISKIYOU
NATIONAL
FOREST
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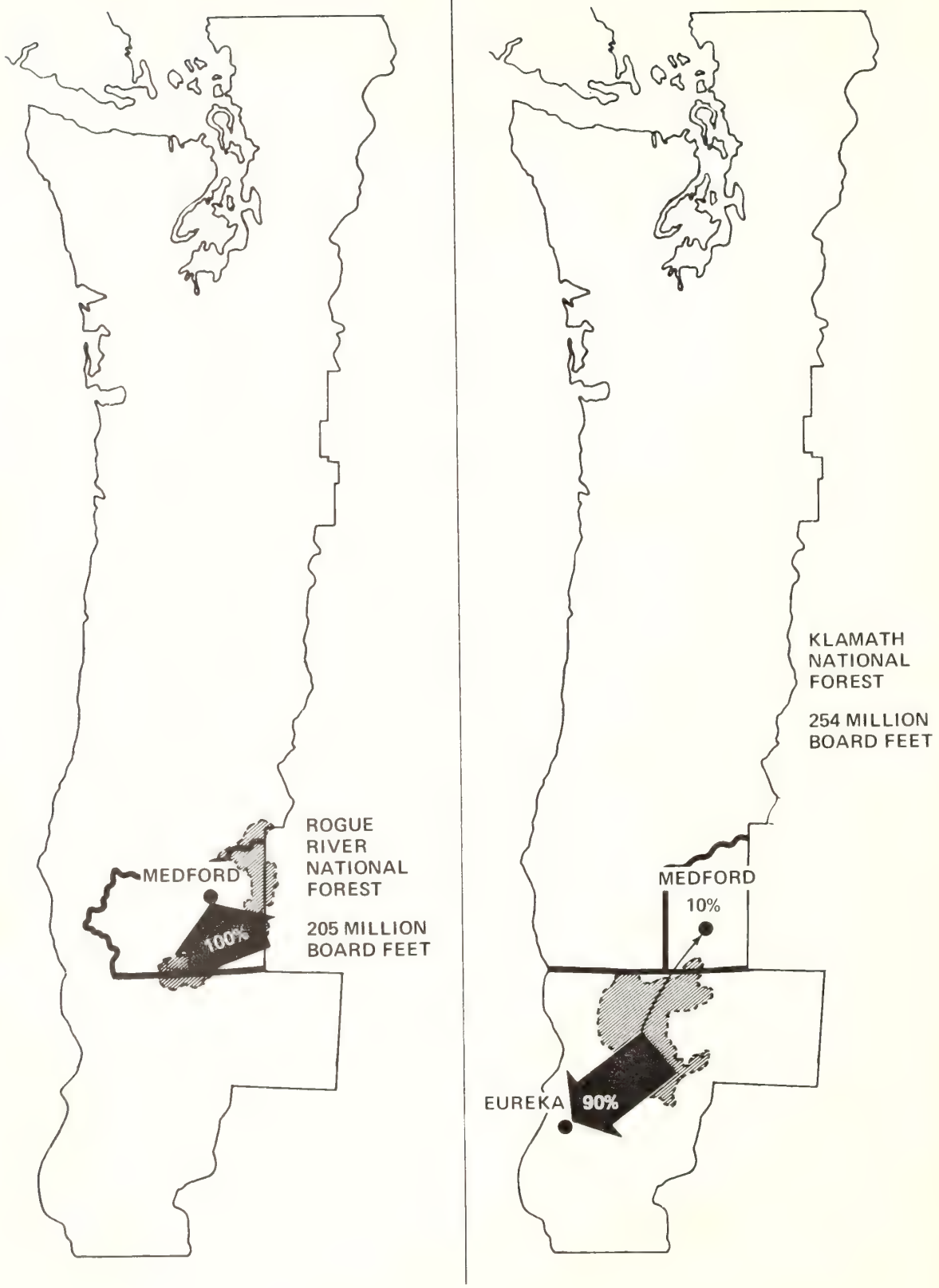
BOARD FEET
EUREKA
2%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RIVER
NATIONAL
FOREST
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MEDFORD
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KLAMATH
NATIONAL
FOREST
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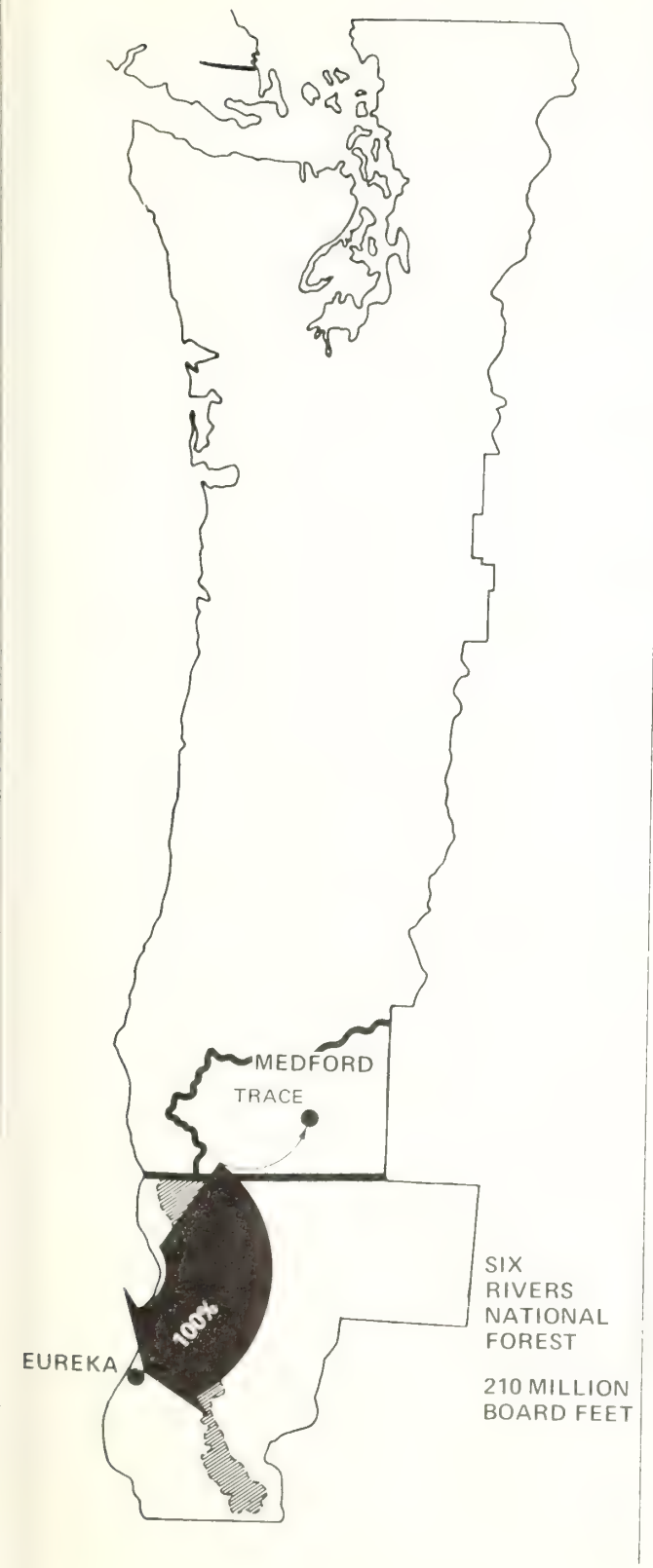
BOARD FEET
MEDFORD
10%
EUREKA
90%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TRACE
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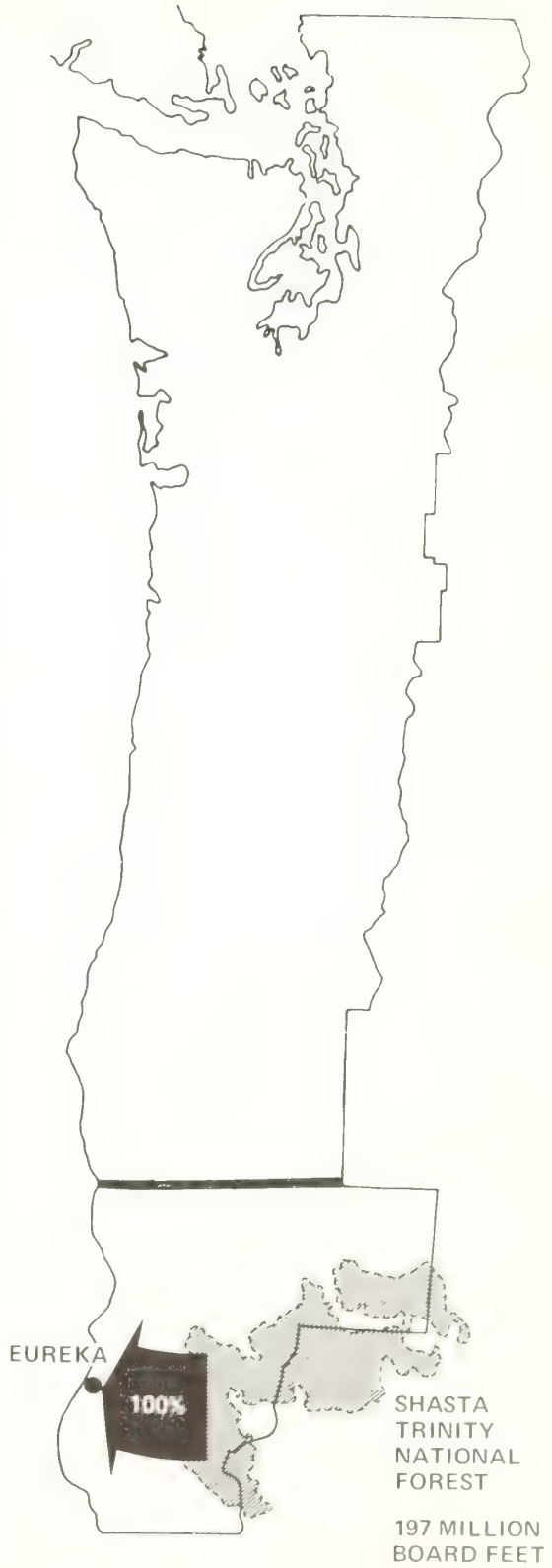
EUREKA
SIX
RIVERS
NATIONAL
FOREST
210 MILLION
BOARD FEET


EUREKA
100%
SHASTA
TRINITY
NATIONAL
FOREST
197 MILLION
BOARD FEET

APPENDIX

Table 13. — Number of active wood product plants by type of plant and county, Douglas-fir region, 1966

State and county	Shake and shingle	Sawmills[1]					Veneer	Veneer and plywood[2]	Plywood	Pulp	Total
		D	C	B	A	Total					
California:											
Del Norte	--	--	3	2	2	7	3	2	--	--	12
Humboldt	1	1	8	15	11	35	3	7	--	2	48
Siskiyou	--	--	3	7	3	13	1	1	--	--	15
Trinity	--	--	3	2	1	6	1	--	--	--	7
Total	1	1	17	26	17	61	8	10	--	2	82
Oregon:											
Benton	--	2	4	2	2	10	2	--	3	1	16
Clackamas	--	7	6	1	4	18	1	1	--	2	22
Clatsop	1	3	--	2	--	5	--	1	--	--	7
Columbia	--	--	2	1	4	7	--	1	--	2	10
Coos	--	1	3	3	3	10	3	8	--	2	23
Curry	--	2	--	2	2	6	1	4	--	--	11
Douglas	--	5	7	10	3	25	9	7	2	1	44
Hood River	--	--	1	2	1	4	--	--	--	1	5
Jackson	--	1	1	7	2	11	2	4	4	--	21
Josephine	--	2	1	2	3	8	--	2	4	--	14
Lane	1	5	15	11	10	41	13	18	5	1	79
Lincoln	--	2	3	2	1	8	1	1	--	1	11
Linn	--	4	2	1	3	10	3	7	3	2	25
Marion	--	1	2	5	--	8	1	2	1	1	13
Multnomah	--	1	3	1	1	6	2	3	1	1	13
Polk	--	2	2	2	1	7	1	3	--	--	11
Tillamook	--	3	1	1	1	6	--	2	--	--	8
Washington	--	2	2	1	--	5	1	--	--	1	7
Yamhill	--	3	2	3	--	8	1	1	2	1	13
Total	2	46	57	59	41	203	41	65	25	17	353
Washington:											
Clallam	6	7	--	--	1	8	--	1	--	3	18
Clark	2	4	1	1	--	6	--	2	--	2	12
Cowlitz	3	4	2	1	2	9	--	2	--	3	17
Grays Harbor	8	3	2	1	2	8	--	6	1	2	25
Island	--	3	--	--	--	3	--	--	--	--	3
Jefferson	1	4	--	--	--	4	1	--	--	1	7
King	1	12	--	2	3	17	--	3	--	--	21
Kitsap	--	5	--	--	1	6	--	--	--	--	6
Lewis	5	9	7	--	1	17	5	1	--	1	29
Mason	--	--	--	--	1	1	1	--	--	1	3
Pacific	7	--	--	--	2	2	--	--	--	--	9
Pierce	2	5	2	3	1	11	--	4	2	2	21
San Juan	--	4	--	--	--	4	--	--	--	--	4
Skagit	7	4	1	--	--	5	--	1	--	1	14
Skamania	--	1	--	--	1	2	2	1	--	--	5
Snohomish	2	12	4	2	1	19	1	1	1	3	27
Thurston	--	6	1	1	--	8	--	1	3	--	12
Wahkiakum	1	1	--	--	--	1	--	--	--	--	2
Whatcom	1	1	1	--	--	2	--	1	--	1	5
Total	46	85	21	11	16	133	10	24	7	20	240
Total, Douglas-fir region	49	132	95	96	74	397	59	99	32	39	675

[1] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

[2] *Integrated operations producing both veneer and plywood.*

Table 14. — Plant capacities by type of plant and county, Douglas-fir region, 1966

State and county	Shake and shingle	Sawmills[1]					Veneer, 1/8-inch	Veneer and plywood, 3/8-inch[2]	Plywood, 3/8-inch	Pulp
		D	C	B	A	Total				
		Thousand bd. ft. per 8-hour shift					*Thousand sq. ft. per 8-hour shift*			*Tons per 24 hours*
California:										
Del Norte	--	--	220	190	305	715	341	501	-	
Humboldt	11	10	493	1,380	1,920	3,803	465	1,016	-	1,000
Siskiyou	--	--	195	658	625	1,478	165	280	-	
Trinity	--	--	219	190	160	569	140	--	--	--
Total	11	10	1,127	2,418	3,010	6,565	1,111	1,797	--	1,000
Oregon:										
Benton	--	59	245	180	295	779	296	--	664	100
Clackamas	--	141	315	115	634	1,205	80	480	--	1,150
Clatsop	9	53	--	210	--	263	--	300	-	--
Columbia	--	--	125	90	730	945	--	165	-	550
Coos	--	14	155	280	960	1,409	670	1,673	-	325
Curry	--	15	--	225	274	514	180	920	--	--
Douglas	--	110	413	921	395	1,839	1,370	1,254	275	500
Hood River	--	--	68	180	120	368	--	--	--	100
Jackson	--	15	50	685	425	1,175	700	1,481	730	--
Josephine	--	50	65	210	450	775	--	410	1,232	--
Lane	15	130	840	1,005	1,940	3,915	1,712	3,381	872	1,150
Lincoln	--	30	152	190	160	532	120	155	--	832
Linn	--	89	115	100	505	809	447	916	1,574	617
Marion	--	1	105	461	--	567	123	262	272	230
Multnomah	--	22	200	80	180	482	71	545	30	30
Polk	--	45	144	200	145	534	32	550	--	--
Tillamook	--	36	50	93	160	339	--	285	--	-
Washington	--	15	150	100	--	265	114	--	--	90
Yamhill	--	54	133	270	--	457	60	160	71	166
Total	24	879	3,325	5,595	7,373	17,172	5,975	12,937	5,720	5,840
Washington:										
Clallam	115	63	--	--	125	188	--	200	-	1,052
Clark	12	80	150	100	--	330	--	640	-	1,350
Cowlitz	28	121	110	100	575	906	--	386	-	3,111
Grays Harbor	67	70	110	90	305	575	--	434	150	885
Island	--	47	--	-	--	47	--	--	--	-
Jefferson	10	48	--	--	--	48	100	--	-	500
King	8	149	--	200	620	969	--	343	--	
Kitsap	--	54	--	--	188	242	--	--	-	
Lewis	53	124	415	--	130	669	503	136	--	40
Mason	--	--	--	-	282	282	260	--	--	100
Pacific	230	--	--	--	375	375	--	--	--	--
Pierce	4	53	130	290	150	623	--	513	92	1,330
San Juan	-	20	--	--	--	20	--		-	-
Skagit	38	81	65	-	--	146	--	175	-	140
Skamania	--	38	--	--	120	158	268	240	-	-
Snohomish	22	190	255	180	500	1,125	57	167	60	1,435
Thurston	--	73	40	116	--	229	--	100	108	--
Wahkiakum	3	4	--	--	--	4	--	-	--	-
Whatcom	8	16	40	--	--	56	--	100	--	500
Total	598	1,231	1,315	1,076	3,370	6,992	1,188	3,434	710	10,443
Total, Douglas-fir region	633	2,120	5,767	9,089	13,753	30,729	8,274	18,168	6,430	17,283

[1] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift, B = 80,000-119,000, C = 40,000-79,000, D = less than 40,000*

[2] *Integrated operations producing both veneer and plywood*

Table 15. — Number of shake and shingle mills listed and responding, capacities of responding mills, and percent of capacity operating on logs, by county, for western Washington, 1966

County	Total number of mills listed	Number of mills responding	Capacities of responding mills	Percent of capacity operating on logs
		Thousand bd. ft. per 8-hour shift		
Washington:				
Clallam	14	6	115	100.0
Clark	2	2	12	94.6
Cowlitz	7	3	28	96.4
Grays Harbor	66	8	67	98.5
Island	0	0	--	--
Jefferson	5	1	10	95.0
King	4	1	3	100.0
Kitsap	0	0	--	--
Lewis	11	5	53	90.0
Mason	1	0	--	--
Pacific	9	7	230	100.0
Pierce	3	2	4	58.0
San Juan	0	0	--	--
Skagit	28	7	38	100.0
Skamania	0	0	--	--
Snohomish	25	2	22	100.0
Thurston	0	0	--	--
Wahkiakum	2	1	3	90.0
Whatcom	8	1	8	100.0
Total	185	46	593	98.3

Table 16. — Volume of logs used by county and type of plant, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	--	71,000	121,000	192,000	104,959	--	296,959
Humboldt	500	104,529	829,570	934,099	207,933	--	1,142,532
Siskiyou	--	61,500	373,501	435,001	[3]	--	[3]
Trinity	--	52,820	104,905	157,725	[3]	--	[3]
Total	500	289,849	1,428,976	1,718,825	400,581	--	2,119,906
Oregon:							
Benton	--	71,410	104,551	175,961	[3]	--	214,461
Clackamas	--	68,778	142,294	211,072	[3]	[3]	325,971
Clatsop	1,878	7,250	[3]	[3]	[3]	--	105,064
Columbia	--	[3]	[3]	223,265	[3]	[3]	257,211
Coos	--	46,661	388,955	435,616	367,154	[3]	[3]
Curry	--	[3]	[3]	105,578	133,826	--	239,404
Douglas	--	93,575	328,852	422,427	487,272	--	909,699
Hood River	--	[3]	[3]	[3]	--	--	109,491
Jackson	--	[3]	[3]	389,556	266,444	--	656,000
Josephine	--	17,099	119,714	136,813	[3]	--	[3]
Lane	9,000	186,340	714,076	900,416	784,367	--	1,693,785
Lincoln	--	27,865	52,801	80,666	[3]	--	134,054
Linn	--	23,967	151,200	175,176	300,570	--	475,737
Marion	--	17,579	142,023	159,602	74,789	--	234,391
Multnomah	--	[3]	[3]	[3]	86,674	--	185,674
Polk	--	27,137	94,500	121,637	118,143	--	239,780
Tillamook	--	16,209	[3]	[3]	[3]	--	155,837
Washington	--	28,710	[3]	[3]	[3]	--	67,210
Yamhill	--	54,736	62,967	117,703	[3]	[3]	173,926
Total	10,878	799,613	3,273,360	4,072,973	2,971,665	153,723	7,209,239
Washington:							
Clallam	25,264	[3]	[3]	[3]	[3]	206,710	311,261
Clark	123	[3]	[3]	[3]	[3]	[3]	260,098
Cowlitz	8,243	50,529	398,696	449,225	[3]	142,368	[3]
Grays Harbor	16,224	28,858	141,171	170,029	58,613	[3]	[3]
Island	--	10,000	--	10,000	--	--	10,000
Jefferson	[3]	8,000	--	8,000	[3]	[3]	43,500
King	1,500	19,851	251,000	270,851	67,915	--	340,266
Kitsap	--	[3]	[3]	34,774	--	--	34,774
Lewis	13,215	[3]	[3]	[3]	108,200	2,400	280,261
Mason	--	3,000	[3]	[3]	[3]	--	168,000
Pacific	30,094	--	[3]	[3]	--	--	[3]
Pierce	293	38,211	148,000	186,211	105,323	[3]	[3]
San Juan	--	900	--	900	--	--	900
Skagit	11,730	38,420	--	38,420	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	48,695	--	[3]
Snohomish	3,800	87,495	325,000	412,495	[3]	323,839	[3]
Thurston	--	11,018	[3]	[3]	[3]	--	43,713
Wahkiakum	[3]	[3]	--	[3]	--	--	[3]
Whatcom	1,920	[3]	--	[3]	[3]	[3]	173,429
Total	116,971	494,871	1,669,258	2,164,129	774,629	1,334,469	4,390,198
Total, Douglas-fir region	128,349	1,584,333	6,371,594	7,955,927	4,146,875	1,488,192	13,719,343

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 17. — Volume of National Forest logs used by county and type of plant, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	--	14,000	--	14,000	28,383	--	42,383
Humboldt	--	16,157	153,904	170,061	37,635	--	207,696
Siskiyou	--	44,850	165,485	210,335	[3]	--	[3]
Trinity	--	26,933	83,879	110,812	[3]	--	[3]
Total	--	101,940	403,268	505,208	132,776	--	637,984
Oregon:							
Benton	--	32,399	33,882	66,281	[3]	--	75,931
Clackamas	--	52,478	108,895	161,373	[3]	[3]	212,983
Clatsop	--	--	[3]	[3]	[3]	--	13,033
Columbia	--	[3]	[3]	19,770	[3]	[3]	19,770
Coos	--	1,509	19,713	21,220	48,032	[3]	[3]
Curry	--	[3]	[3]	33,952	45,050	--	79,002
Douglas	--	38,377	108,288	146,665	194,775	--	341,440
Hood River	--	[3]	[3]	[3]	--	--	89,468
Jackson	--	[3]	[3]	177,872	110,752	--	228,624
Josephine	--	1,084	76,231	77,315	[3]	--	[3]
Lane	3,600	101,241	257,850	359,091	400,240	--	762,931
Lincoln	--	4,074	12,192	16,266	[3]	--	21,216
Linn	--	19,278	60,588	79,866	79,727	--	159,593
Marion	--	3,000	95,786	98,786	49,035	--	147,821
Multnomah	--	[3]	[3]	[3]	36,787	--	88,607
Polk	--	--	13,850	13,850	7,168	--	21,018
Tillamook	--	--	[3]	[3]	[3]	--	19,439
Washington	--	--	[3]	[3]	[3]	--	--
Yamhill	--	16,608	30,323	46,931	[3]	[3]	61,235
Total	3,600	292,229	1,175,286	1,467,515	1,085,265	11,305	2,567,685
Washington:							
Clallam	1,363	[3]	[3]	[3]	[3]	17,239	46,592
Clark	13	[3]	[3]	[3]	[3]	[3]	53,287
Cowlitz	41	18,960	24,560	43,520	[3]	2,731	[3]
Grays Harbor	3,374	500	57,650	58,150	24,970	[3]	[3]
Island	--	--	--	--	--	--	--
Jefferson	[3]	--	--	--	[3]	[3]	4,200
King	750	5,428	45,790	51,218	17,816	--	69,784
Kitsap	--	[3]	[3]	9,984	--	--	9,984
Lewis	283	[3]	[3]	[3]	65,300	--	151,734
Mason	--	--	[3]	[3]	[3]	--	101,500
Pacific	--	--	[3]	[3]	--	--	[3]
Pierce	75	13,500	24,360	37,860	53,749	[3]	[3]
San Juan	--	--	--	--	--	--	--
Skagit	3,863	15,850	--	15,850	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	45,958	--	[3]
Snohomish	2,625	37,804	67,900	105,704	[3]	70,276	[3]
Thurston	--	--	[3]	[3]	[3]	--	17,804
Wahkiakum	[3]	[3]	--	[3]	--	--	[3]
Whatcom	672	[3]	--	[3]	[3]	[3]	77,942
Total	13,059	164,848	380,810	545,658	383,675	212,138	1,154,530
Total, Douglas-fir region	16,659	559,017	1,959,364	2,518,381	1,601,716	223,443	4,360,199

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift.*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 18. — Volume of Bureau of Land Management logs used by county and plant type, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	--	--	--	--	--	--	--
Humboldt	--	5,300	12,940	18,240	--	--	18,240
Siskiyou	--	--	--	--	--	--	[3]
Trinity	--	2,880	--	2,880	--	--	[3]
Total	--	8,180	12,940	21,120	--	--	21,120
Oregon:							
Benton	--	15,210	39,235	54,445	[3]	--	71,695
Clackamas	--	--	508	5,800	[3]	[3]	11,317
Clatsop	--	--	[3]	[3]	[3]	--	--
Columbia	--	[3]	[3]	--	[3]	[3]	--
Coos	--	9,433	39,130	48,563	70,177	[3]	[3]
Curry	--	[3]	[3]	855	756	--	1,611
Douglas	--	15,696	99,781	115,477	125,811	--	241,348
Hood River	--	[3]	[3]	[3]	--	--	--
Jackson	--	[3]	[3]	83,352	57,090	--	140,442
Josephine	--	11,647	37,283	48,930	[3]	--	[3]
Lane	1,800	44,586	70,512	115,098	97,933	--	214,831
Lincoln	--	4,791	--	4,791	[3]	--	4,791
Linn	--	146	20,360	20,506	46,187	--	66,693
Marion	--	3,000	17,750	20,750	3,899	--	24,649
Multnomah	--	[3]	[3]	[3]	440	--	2,250
Polk	--	--	23,160	23,160	25,062	--	48,222
Tillamook	--	--	[3]	[3]	[3]	--	21,752
Washington	--	--	[3]	[3]	[3]	--	14,025
Yamhill	--	7,427	10,074	17,501	[3]	[3]	34,966
Total	1,800	127,406	450,400	577,806	492,684	12,119	1,084,409
Washington:							
Clallam	--	[3]	[3]	[3]	[3]	--	--
Clark	--	[3]	[3]	[3]	[3]	[3]	--
Cowlitz	--	480	--	480	[3]	--	[3]
Grays Harbor	--	--	--	--	--	[3]	[3]
Island	--	--	--	--	--	--	--
Jefferson	[3]	--	--	--	[3]	[3]	--
King	--	--	--	--	--	--	--
Kitsap	--	[3]	[3]	--	--	--	-
Lewis	--	[3]	[3]	[3]	--	--	--
Mason	--	--	[3]	[3]	[3]	--	--
Pacific	--	--	[3]	[3]	--	--	[3]
Pierce	--	--	--	--	--	[3]	[3]
San Juan	--	--	--	--	--	--	--
Skagit	--	--	--	--	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	--	--	[3]
Snohomish	--	--	--	--	[3]		[3]
Thurston	--	--	[3]	[3]	[3]	--	--
Wahkiakum	[3]	[3]	--	[3]	--	--	[3]
Whatcom	--	[3]	--	[3]	[3]	[3]	--
Total	--	480	--	480	3,000	--	3,480
Total, Douglas-fir region	1,800	136,066	463,340	599,406	495,684	12,119	1,109,009

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift.*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 19. — Volume of Bureau of Indian Affairs logs used by county and plant type, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	--	--	--	--	--	--	--
Humboldt	--	--	12,500	12,500	23,154	--	35,654
Siskiyou	--	--	--	--	[3]	--	[3]
Trinity	--	--	4,500	4,500	[3]	--	[3]
Total	--	--	17,000	17,000	25,074	--	42,074
Oregon:							
Benton	--	--	--	--	[3]	--	--
Clackamas	--	--	--	--	[3]	[3]	--
Clatsop	--	--	[3]	[3]	[3]	--	--
Columbia	--	[3]	[3]	--	[3]	[3]	--
Coos	--	--	--	--	--	[3]	[3]
Curry	--	[3]	[3]	--	--	--	--
Douglas	--	--	--	--	--	--	--
Hood River	--	[3]	[3]	[3]	--	--	--
Jackson	--	[3]	[3]	--	--	--	--
Josephine	--	--	--	--	[3]	--	[3]
Lane	--	--	--	--	--	--	--
Lincoln	--	--	--	--	[3]	--	--
Linn	--	--	--	--	--	--	--
Marion	--	--	--	--	--	--	--
Multnomah	--	[3]	[3]	[3]	--	--	2,600
Polk	--	--	--	--	--	--	--
Tillamook	--	[3]	[3]	--	[3]	--	--
Washington	--	--	[3]	[3]	[3]	--	--
Yamhill	--	--	--	--	[3]	[3]	--
Total	--	2,600	--	2,600	--	--	2,600
Washington:							
Clallam	--	[3]	[3]	[3]	[3]	5,220	5,796
Clark	--	[3]	[3]	[3]	[3]	[3]	--
Cowlitz	--	--	--	--	[3]	--	[3]
Grays Harbor	11,428	1,443	--	1,433	--	[3]	[3]
Island	--	--	--	--	--	--	--
Jefferson	[3]	--	--	--	[3]	[3]	--
King	--	--	2,900	2,900	--	--	2,900
Kitsap	--	[3]	[3]	--	--	--	--
Lewis	4,125	[3]	[3]	[3]	--	--	4,745
Mason	--	--	[3]	[3]	[3]	--	--
Pacific	--	--	--	[3]	[3]	--	[3]
Pierce	--	3,600	--	3,600	--	[3]	[3]
San Juan	--	--	--	--	--	--	--
Skagit	--	1,300	--	1,300	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	[3]	--	[3]
Snohomish	--	11	--	11	[3]	--	[3]
Thurston	--	--	[3]	[3]	[3]	--	[3]
Wahkiakum	[3]	[3]	--	[3]	--	--	--
Whatcom	--	[3]	--	[3]	[3]	[3]	130
Total	15,553	7,680	2,900	10,580	5,813	34,400	66,346
Total, Douglas-fir region	15,553	10,280	19,900	30,180	30,887	34,400	111,020

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift.*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 20. — Volume of State logs used by county and plant type, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	--	--	--	--	--	--	--
Humboldt	--	--	--	--	--	--	--
Siskiyou	--	--	--	--	--	--	--
Trinity	--	--	--	--	--	--	--
Total	--	--	--	--	--	--	--
Oregon:							
Benton	--	1,925	--	1,925	[3]	[3]	3,875
Clackamas	--	--	--	--	[3]	[3]	6,715
Clatsop	--	2,000	[3]	[3]	[3]	--	15,111
Columbia	--	[3]	[3]	16,390	[3]	[3]	16,390
Coos	--	27,167	38,402	65,569	9,540	[3]	[3]
Curry	--	[3]	[3]	900	--	--	900
Douglas	--	614	1,075	1,689	1,073	--	2,762
Hood River	--	[3]	[3]	[3]	--	--	4,350
Jackson	--	[3]	[3]	513	372	--	885
Josephine	--	--	1,800	1,800	[3]	--	[3]
Lane	--	489	4,944	5,433	275	--	5,708
Lincoln	--	252	4,510	4,762	[3]	[3]	4,762
Linn	--	--	--	--	4,097	--	4,097
Marion	--	1,000	990	1,990	1,800	--	3,790
Multnomah	--	[3]	[3]	[3]	10,245	--	11,165
Polk	--	3,150	4,000	7,150	1,768	--	8,918
Tillamook	--	--	[3]	[3]	[3]	--	19,887
Washington	--	2,480	[3]	[3]	[3]	--	11,915
Yamhill	--	1,457	1,500	2,957	[3]	[3]	4,696
Total	--	42,034	101,893	143,927	50,454	12,194	206,575
Washington:							
Clallam	2,331	[3]	[3]	[3]	[3]	24,296	54,015
Clark	--	[3]	[3]	[3]	[3]	[3]	14,911
Cowlitz	21	4,012	30,462	34,474	[3]	8,192	[3]
Grays Harbor	480	3,000	10,850	13,850	5,910	[3]	[3]
Island	--	--	--	--	--	--	--
Jefferson	[3]	200	--	200	[3]	[3]	12,300
King	--	4,530	11,200	15,730	--	--	15,730
Kitsap	--	[3]	[3]	3,590	--	--	3,590
Lewis	3,995	[3]	[3]	[3]	31,720	--	44,085
Mason	--	--	[3]	[3]	[3]	--	--
Pacific	260	--	[3]	[3]	--	--	[3]
Pierce	--	4,350	12,570	16,920	15,466	[3]	[3]
San Juan	--	--	--	--	--	--	--
Skagit	1,200	6,500	--	6,500	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	--	--	[3]
Snohomish	875	7,707	8,000	15,707	[3]	25,702	[3]
Thurston	--	660	[3]	[3]	[3]	--	6,980
Wahkiakum	[3]	[3]	--	[3]	--	--	[3]
Whatcom	288	[3]	--	[3]	[3]	[3]	15,737
Total	9,450	45,936	105,344	151,280	98,490	104,010	363,230
Total, Douglas-fir region	9,450	87,970	207,237	295,207	148,944	116,204	569,805

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift.*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 21. — Volume of logs used from company owned land supplying own mills by county and plant type, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	--	50,500	47,000	97,500	35,577	--	133,077
Humboldt	--	41,532	318,427	359,959	107,769	--	467,728
Siskiyou	--	2,425	141,952	144,377	[3]	--	[3]
Trinity	--	1,046	6,600	7,646	[3]	--	[3]
Total	--	95,503	513,979	609,482	154,703	--	764,185
Oregon:							
Benton	--	3,897	5,822	9,719	[3]	--	18,604
Clackamas	--	1,103	12,470	13,573	[3]	[3]	46,889
Clatsop	--	--	[3]	[3]	[3]	--	--
Columbia	--	[3]	[3]	60,066	[3]	[3]	88,012
Coos	--	3,600	214,350	217,950	210,296	[3]	[3]
Curry	--	[3]	[3]	33,625	73,786	--	107,411
Douglas	--	4,325	48,729	53,054	120,618	--	173,672
Hood River	--	[3]	[3]	[3]	--	--	13,089
Jackson	--	[3]	[3]	56,107	68,960	--	125,067
Josephine	--	--	400	400	[3]	--	[3]
Lane	--	5,000	295,967	300,967	227,751	--	528,718
Lincoln	--	4,821	7,632	12,453	[3]	--	60,341
Linn	--	--	48,252	48,258	121,160	--	169,412
Marion	--	861	990	1,851	1,065	--	2,916
Multnomah	--	[3]	[3]	[3]	3,740	--	9,180
Polk	--	1,527	23,930	25,457	43,960	--	69,417
Tillamook	--	400	[3]	[3]	[3]	--	6,223
Washington	--	3,533	[3]	[3]	[3]	--	13,872
Yamhill	--	9,841	5,476	15,317	[3]	[3]	29,293
Total	--	43,296	827,956	871,252	977,885	41,889	1,891,026
Washington:							
Clallam	150	[3]	[3]	[3]	[3]	125,929	129,586
Clark	6	[3]	[3]	[3]	[3]	[3]	110,381
Cowlitz	--	1,749	305,702	307,451	[3]	85,583	[3]
Grays Harbor	--	500	59,171	59,671	1,130	[3]	[3]
Island	--	4,900	--	4,900	--	--	4,900
Jefferson	[3]	--	--	[3]	[3]	[3]	4,900
King	--	22	164,800	164,822	39,882	--	2,100
Kitsap	--	[3]	[3]	8,245	--	--	204,644
Lewis	--	[3]	[3]	[3]	3,250	--	8,245
Mason	--	--	[3]	[3]	[3]	--	11,543
Pacific	10,973	--	[3]	[3]	--	--	[3]
Pierce	--	2,800	59,500	62,300	23,261	[3]	[3]
San Juan	--	110	--	110	--	--	147,279
Skagit	--	--	--	--	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	--	--	[3]
Snohomish	--	2,440	244,200	246,640	[3]	175,580	[3]
Thurston	--	170	[3]	[3]	[3]	--	3,832
Wahkiakum	[3]	[3]	--	[3]	--	--	[3]
Whatcom	--	[3]	--	[3]	[3]	[3]	24,065
Total	11,129	21,179	972,818	993,997	171,192	715,287	1,891,605
Total, Douglas-fir region	11,129	159,978	2,314,753	2,474,731	1,303,780	757,176	4,546,816

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift.*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 22. — Volume of purchased private logs used by county and plant type, Douglas-fir region, 1966

(Thousand board feet, Scribner log rule)

State and county	Shake and shingle	Sawmills[1]			Plywood[2]	Pulp	Total
		D and C	B and A	Total			
California:							
Del Norte	–	6,500	74,000	80,500	40,999	--	121,499
Humboldt	500	41,540	331,799	373,339	39,375	--	413,214
Siskiyou	--	14,225	66,064	80,289	[3]	--	[3]
Trinity	–	21,961	9,926	31,887	[3]	--	[3]
Total	500	84,226	481,789	566,015	88,028	--	654,543
Oregon:							
Benton	--	17,979	25,612	43,591	[3]	--	44,356
Clackamas	--	15,197	15,129	30,326	[3]	[3]	48,067
Clatsop	1,878	5,250	[3]	[3]	[3]	--	77,720
Columbia	--	[3]	[3]	127,039	[3]	[3]	133,039
Coos	--	4,952	77,360	82,312	29,109	[3]	[3]
Curry	--	[3]	[3]	36,246	14,234	--	50,480
Douglas	–	34,563	70,979	105,542	44,935	--	150,477
Hood River	--	[3]	[3]	[3]	--	--	2,584
Jackson	--	[3]	[3]	71,712	29,270	--	100,982
Josephine	--	4,368	4,000	8,368	[3]	--	[3]
Lane	3,600	35,024	84,805	119,829	58,168	--	181,597
Lincoln	--	13,927	28,467	42,394	[3]	--	42,944
Linn	–	4,543	22,000	26,543	49,399	--	75,942
Marion	--	9,718	26,507	36,225	18,990	--	55,215
Multnomah	--	[3]	[3]	[3]	35,462	--	71,872
Polk	--	22,460	29,560	52,020	40,185	--	92,205
Tillamook	--	15,809	[3]	[3]	[3]	--	88,536
Washington	–	22,698	[3]	[3]	[3]	--	27,398
Yamhill	–	19,403	15,594	34,997	[3]	[3]	43,736
Total	5,478	292,048	717,825	1,009,873	365,377	76,216	1,456,944
Washington:							
Clallam	21,420	[3]	[3]	[3]	[3]	34,026	75,274
Clark	104	[3]	[3]	[3]	[3]	[3]	81,519
Cowlitz	8,181	25,328	37,972	6,300	[3]	45,862	[3]
Grays Harbor	942	23,415	13,500	39,915	22,040	[3]	[3]
Island	--	5,100	--	5,100	--	--	5,100
Jefferson	[3]	7,800	--	7,800	--	[3]	24,900
King	750	9,871	26,310	36,181	10,277	--	47,208
Kitsap	--	[3]	[3]	12,955	--	--	12,955
Lewis	4,812	[3]	[3]	[3]	7,930	--	68,154
Mason	--	3,000	[3]	[3]	2,500	--	11,250
Pacific	18,861	--	[3]	[3]	--	--	[3]
Pierce	218	13,961	51,570	65,531	9,847	[3]	[3]
San Juan	--	790	--	790	--	--	790
Skagit	6,667	14,770	--	14,770	[3]	[3]	[3]
Skamania	--	[3]	[3]	[3]	--	--	[3]
Snohomish	300	39,533	4,900	44,433	[3]	52,281	[3]
Thurston	--	10,188	[3]	[3]	[3]	--	15,097
Wahkiakum	[3]	[3]	--	[3]	--	--	[3]
Whatcom	960	[3]	--	[3]	[3]	[3]	55,555
Total	67,780	254,748	207,386	462,134	112,459	268,634	911,007
Total, Douglas-fir region	73,758	631,022	1,407,000	2,038,022	565,864	344,850	3,022,494

[1] *Sawmills divided into class D and C with capacity of less than 80,000 board feet per 8-hour shift and class B and A with capacity of 80,000+ board feet per 8-hour shift.*

[2] *Plywood plants include veneer plants and integrated veneer and plywood plants producing both veneer and plywood.*

[3] *Withheld to avoid disclosing data for individual firms.*

Table 23. — Volume of logs used in

(Thousand boa

Log origin by State and county	Clallam	Clark	Cowlitz[1]	Grays Harbor	Island	Jefferson	King	Kitsap	
Oregon:									
Clackamas	--	6,875	30,821	--	--	--	-	--	
Clatsop	--	64,650	1,054	--	--	--	--	--	
Columbia	--	4,975	4,159	--	--	--	--	--	
Lincoln	--	296	--	--	--	--	--	--	
Linn	--	--	--	--	--	--	--	--	
Polk	--	247	--	--	--	--	--	--	
Other, eastern[2]	--	6,875	--	--	--	--	--	--	
Total[3]	--	83,918	36,034	--	--	--	--	--	
Washington:									
Clallam	242,529	--	--	250	--	750	9,000	3,941	
Clark	--	8,526	13,159	--	--	--	--	--	
Cowlitz	--	13,218	351,745	520	--	–	5,000	--	
Grays Harbor	432	--	--	331,193	--	--	5,000	--	
Island	--	--	--	--	10,000	3,000	--	--	
Jefferson	67,507	--	--	32,106	--	31,350	25,408	10,846	
King	--	--	--	--	--	2,100	220,665	--	
Kitsap	--	--	--	--	--	--	--	11,843	
Lewis	--	12,600	158,897	2,400	--	--	27,757	--	2
Mason	--	--	--	1,426	--	2,100	2,700	2,802	
Pacific	--	22,691	70,820	77,761	--	--	--	--	
Pierce	--	--	--	--	--	2,100	4,973	350	
San Juan	--	--	--	--	--	--	--	--	
Skagit	795	--	--	--	--	--	3,150	--	
Skamania	--	97,111	37,881	--	--	--	--	--	
Snohomish	--	--	--	--	--	--	2,696	--	
Thurston	--	--	--	--	--	2,100	817	--	
Wahkiakum	--	22,035	25,701	--	--	--	--	--	
Whatcom	--	--	--	--	--	--	6,750	4,992	
Other, eastern[2]	--	--	420	--	--	--	24,350	--	
Total[3]	311,263	176,181	658,623	445,656	10,000	43,500	338,266	34,774	2
Idaho and Canada	--	--	--	--	--	--	2,000	--	
Total[3]	311,263	260,099	694,657	445,656	10,000	43,500	340,266	34,774	2

[1] *Does not contain 6,181,000 board feet of pole and piling obtained from Cowlitz, Lewis, Pacific, Skamania, and Clackamas Counties.*

[2] *Other eastern Oregon and eastern Washington log volumes came from Wasco, Kittitas, Klickitat, Yakima, and Chelan Counties. 14,525,000 board feet of the volume comes from unknown west-side origin*

[3] *Totals shown may not agree exactly with totals in other tables due to rounding.*

ington counties, by county of origin, 1966

ner log rule)

ation

son	Pacific	Pierce	San Juan	Skagit	Skamania	Snohomish	Thurston	Wahkiakum	Whatcom	Total
--	--	--	--	--	2,500	--	--	--	--	40,196
--	--	--	--	--	--	--	676	--	--	66,380
--	--	--	--	--	--	--	676	--	--	9,810
--	--	--	--	--	--	--	--	--	--	296
--	--	18,000	--	--	--	--	--	--	--	18,000
--	--	--	--	--	--	--	--	--	--	247
--	--	--	--	--	--	--	--	--	--	6,875
--	--	18,000	--	--	2,500	--	1,352	--	--	141,804
--	--	5,980	--	--	--	6,242	--	--	--	268,692
--	--	--	--	--	--	--	--	--	--	21,685
--	--	722	--	--	--	--	3,370	--	--	394,615
900	13,662	25,440	--	--	--	--	1,500	--	--	444,376
--	--	--	--	4,805	--	--	--	--	--	17,805
--	--	--	--	15,000	--	10,752	1,580	--	--	194,549
--	--	14,255	--	8,000	--	69,019	4,393	--	4,011	322,689
--	--	4,600	--	1,500	--	--	790	--	--	18,733
--	4,306	117,425	--	8,000	--	141,600	8,467	--	--	684,127
200	--	17,950	--	--	--	--	790	--	--	133,041
--	133,109	2,166	--	--	--	--	--	39	--	307,945
300	--	177,906	--	--	--	58,035	705	--	--	250,305
--	--	--	900	--	--	--	--	--	--	900
--	--	--	--	59,785	--	89,079	--	--	56,181	208,990
--	--	12,000	--	--	94,245	1,325	1,352	--	--	279,682
--	--	--	--	28,310	--	200,309	6,082	--	9,619	247,016
300	--	11,484	--	--	--	138,000	13,332	--	--	173,882
--	2,453	--	--	--	--	--	--	76	--	50,765
--	--	--	--	14,750	--	27,780	--	--	72,869	127,141
--	--	--	--	--	--	28,216	--	--	--	53,850
3,100	153,530	389,928	900	140,150	94,245	770,357	42,361	115	142,680	4,200,788
--	--	--	--	--	--	14,859	--	--	30,750	47,609
3,100	153,530	407,928	900	140,150	96,745	785,216	43,713	115	173,430	4,390,201

Table 24. — Volume of logs used in w
(Thousand boa

Log origin by State and county	Benton	Clackamas	Clatsop	Columbia	Coos	Curry	Douglas	Hood River	J
California:									
Del Norte	--	--	--	--	--	--	--	--	
Humboldt	--	--	--	--	--	5,161	--	--	
Siskiyou	--	--	--	--	--	--	--	--	
Total[2]	--	--	--	--	--	5,161	--	--	
Oregon:									
Benton	88,841	3,200	--	10,180	--	--	--	--	
Clackamas	--	233,879	8,080	17,870	--	--	--	1,254	
Clatsop	--	12,397	58,453	41,097	--	--	--	--	
Columbia	--	--	--	75,295	--	--	--	--	
Coos	-	--	--	--	605,618	5,392	9,248	--	
Curry	--	--	--	--	116,637	228,851	11,873	--	
Douglas	--	1,600	--	--	141,559	--	879,661	--	
Hood River	--	--	--	--	--	--	--	58,826	
Jackson	--	--	--	--	1,616	--	1,079	--	4
Josephine	--	3,200	--	--	--	--	5,936	--	
Lane	38,698	6,400	--	--	--	-	1,901	--	
Lincoln	72,799	10,025	--	--	--	--	--	--	
Linn	1,200	1,500	--	--	--	--	--	--	
Marion	--	5,560	--	--	--	--	--	--	
Multnomah	-	23,129	--	-	--	--	--	--	
Polk	12,925	1,937	--	--	--	--	--	--	
Tillamook	--	6,198	751	--	--	--	--	--	
Washington	--	--	--	--	--	--	--	--	
Yamhill	--	--	--	--	--	--	--	--	
Other, eastern[3]	--	4,216	--	--	--	--	--	1,630	
Total[2]	214,463	313,241	67,284	144,442	865,430	234,243	909,698	61,710	6
Washington:									
Clallam	--	1,620	--	--	--	--	--	--	
Clark	--	--	--	--	--	--	--	--	
Cowlitz	--	--	6,516	46,180	--	--	--	--	
Grays Harbor	--	--	-	6,300	--	--	--	--	
Lewis	--	--	-	29,700	--	--	--	--	
Pacific	--	3,487	--	7,395	--	--	--	--	
Skamania	--	3,750	6,516	12,383	-	--	--	47,467	
Wahkiakum	--	3,874	25,547	10,811	--	--	--	--	
Other, eastern[3]	--	--	-	-	--	--	--	314	
Total[2]	--	12,731	38,579	112,769	--	--	--	47,781	
Total[2]	214,463	325,972	105,863	257,211	865,430	239,404	909,698	109,491	6

[1] *Multnomah County also consumed 600,000 board feet that was imported from the Philippines. This volume is not included in the table.*

[2] *Totals shown may not agree exactly with totals in other tables due to rounding.*

[3] *Eastern Oregon and eastern Washington log volumes from Klamath, Wasco, Lake, and Yakima Counties.*

on counties, by county of origin, 1966
ner log rule)

tion

phine	Lane	Lincoln	Linn	Marion	Multnomah[1]	Polk	Tillamook	Washington	Yamhill	Total[2]
--	--	--	--	--	--	--	--	--		
00	--	--	--	--	--	--	--	--	--	8,761
00	--	--	--	--	--	--	--	--	--	38,324
00	--	--	--	--	--	--	--	--	--	47,085
--	4,672	252	3,487	--	--	27,863	--	--	--	138,495
--	--	--	5,500	15,025	65,025	200	--	--	--	346,833
--	--	--	--	--	13,075	--	--	22,625	1,093	148,740
--	--	--	--	--	11,700	--	--	--	--	86,995
--	9,382	--	--	--	--	--	--	--	--	629,640
52	--	--	--	--	--	--	--	--	--	366,213
53	281,067	--	--	--	--	--	--	--	--	1,396,028
--	--	--	--	--	--	--	--	--	--	58,826
42	--	--	--	--	--	--	--	--	--	468,029
56	--	--	--	--	--	--	--	--	--	164,402
--	1,317,400	3,560	72,905	8,486		18,607	1,445	--		1,469,402
--	3,750	130,242	21,625	25,201	--	80,363	31,434	--	56,755	432,194
--	73,011	--	337,481	83,933	4,950	16,575	--	--	--	518,650
--	--	--	34,739	79,166	--	3,800	--	--	1,932	125,197
--	--	--	--	--	8,490	--	--	--	--	31,619
--	--	--	--	16,802	3,240	54,074	--	--	21,278	110,256
--	--	--	--	5,776	9,630	14,294	120,430	14,985	50,496	222,560
--	--	--	--	--	1,500	--	--	22,325	--	23,825
--	--	--	--	--	2,220	24,004	2,528	7,275	42,371	78,398
--	4,500	--	--	--	2,600	--	--	--	--	70,742
3	1,693,782	134,054	475,737	234,389	122,430	239,780	155,837	67,210	173,925	6,887,044
--	--	--	--	--	1,200	--	--	--		2,820
--	--	--	--	--	250	--	--	--	--	250
--	--	--	--	--	6,600	--	--	--	--	59,296
--	--	--	--	--	--	--	--	--	--	6,300
--	--	--	--	--	--	--	--	--	--	29,700
--	--	--	--	--	6,275	--	--	--	--	17,157
--	--	--	--	--	45,150	--	--			115,266
--	--	--	--	--	3,770	--		--	--	44,002
--	--	--	--	--	--	--	--	--	--	314
--	--	--	--	–	63,245	--	--	--	--	275,105
3	1,693,782	134,054	475,737	234,389	185,675	239,780	155,837	67,210	173,925	7,209,234

Table 25. — Volume of logs used in northern California counties, by county of origin, 1966

(Thousand board feet, Scribner log rule)

Log origin by State and county	Log destination				
	Del Norte	Humboldt	Siskiyou	Trinity	Total
California:					
Del Norte	194,234	59,840	--	--	254,074
Humboldt	80,592	994,427	--	41,282	1,116,301
Siskiyou	--	41,427	429,460	--	470,887
Trinity	--	44,798	14,225	148,443	207,466
Other[1]	--	2,040	47,005	--	49,045
Total	274,826	1,142,532	490,690	189,725	2,097,773
Oregon:					
Curry	19,760	--	--	--	19,760
Josephine	2,373	--	--	--	2,373
Total	22,133	--	--	--	22,133
Total	296,959	1,142,532	490,690	189,725	2,119,906

[1] *Other volume from Mendocino, Shasta, and Modoc Counties.*

Table 26. — National Forest logs used, by f

(Thousand board

Type of plant	Deschutes	Fremont	Gifford Pinchot	Klamath	Mount Baker	Mount Hood	Okanogan	Olympic	Ro Ri
Shake and shingle	--	--	178	--	7,160	--	--	4,737	
Sawmills[1]									
D	--	--	22,897	2,800	7,050	12,272	--	590	
C	--	--	70,527	7,650	28,655	52,397	--	4,970	
B	--	--	34,723	145,543	55,000	66,883	--	6,980	106,
A	--	--	138,110	46,193	9,827	116,125	1,350	154,107	13,
Total	–	--	266,257	202,186	100,532	247,677	1,350	166,647	120,
Veneer	--	1,800	67,478	46,995	--	19,290	--	32,500	31,
Veneer and plywood[2]	1,600	--	114,288	4,691	38,469	47,089	--	56,472	53,
Pulp	--	--	19,106	--	100,027	6,800	--	36,623	
Total	1,600	1,800	467,307	253,872	246,188	320,856	1,350	296,979	205,

[1] *Sawmills denoted as follows: class A mills = 120,000+ board feet capacity per 8-hour shift; B = 80,000-119,000; C = 40,000-79,000; D = less than 40,000.*

[2] *Integrated operations producing both veneer and plywood.*

ype of plant, Douglas-fir region, 1966

her log rule)

tional Forest

ta-ity	Siskiyou	Siuslaw	Six Rivers	Snoqualmie	Umpqua	Wenatchee	Willamette	Winema	Total
--	--	1,350	--	834	--	150	2,250	--	16,659
--	600	1,102	--	1,695	--	4,933	3,724	4,200	61,863
35	242	60,201	26,155	25,321	48,806	1,200	102,653	--	497,154
49	18,167	104,709	41,074	30,000	105,078	3,600	162,428	12,900	959,733
53	83,351	66,876	71,920	20,350	51,208	3,650	167,918	1,139	999,631
37	102,360	232,888	139,149	77,366	205,092	13,383	436,723	18,239	2,518,381
20	26,128	51,961	60,914	21,880	140,663	--	171,919	2,898	683,285
07	85,312	54,373	9,741	62,338	107,336	370	279,728	1,100	918,431
--	5,649	1,606	--	53,632	--	--	--	--	223,443
64	219,449	342,178	209,804	216,050	453,091	13,903	890,620	22,237	4,360,199

Table 27. — National Forest logs
(Thousand bo

State and county	Deschutes	Fremont	Gifford Pinchot	Klamath	Mount Baker	Mount Hood	Okanogan	Olympic
California:								
Del Norte	--	--	--	--	--	--	--	--
Humboldt	--	--	--	39,627	--	--	--	--
Siskiyou	--	--	--	187,953	--	--	--	--
Trinity	--	--	--	--	--	--	--	--
Total	--	--	--	227,580	--	--	--	--
Oregon:								
Benton	--	--	--	--	--	--	--	--
Clackamas	1,600	--	3,750	--	--	192,583	--	--
Clatsop	--	--	7,820	--	--	5,213	--	--
Columbia	--	--	14,680	--	--	5,090	--	--
Coos	--	--	--	--	--	--	--	--
Curry	--	--	--	--	--	--	--	--
Douglas	--	--	--	--	--	--	--	--
Hood River	--	--	47,357	--	--	42,111	--	--
Jackson	--	--	--	12,692	--	--	--	--
Josephine	--	--	--	13,600	--	--	--	--
Lane	--	1,800	--	--	--	--	--	--
Lincoln	--	--	--	--	--	--	--	--
Linn	--	--	--	--	--	599	--	--
Marion	--	--	--	--	--	9,503	--	--
Multnomah	--	--	27,890	--	--	60,507	--	--
Polk	--	--	--	--	--	--	--	--
Tillamook	--	--	--	--	--	--	--	--
Washington	--	--	--	--	--	--	--	--
Yamhill	--	--	--	--	--	--	--	--
Total	1,600	1,800	101,497	26,292	--	315,606	--	--
Washington:								
Clallam	--	--	--	--	795	--	--	45,797
Clark	--	--	50,537	--	--	2,750	--	--
Cowlitz	--	--	52,783	--	--	--	--	--
Grays Harbor	--	--	--	--	--	--	--	97,707
Island	--	--	--	--	--	--	--	--
Jefferson	--	--	--	--	--	--	--	4,200
King	--	--	12,059	--	7,200	--	1,350	15,597
Kitsap	--	--	--	--	2,627	--	--	7,357
Lewis	--	--	126,356	--	--	--	--	--
Mason	--	--	--	--	--	--	--	101,500
Pacific	--	--	--	--	--	--	--	--
Pierce	--	--	31,051	--	--	--	--	3,971
San Juan	--	--	--	--	--	--	--	--
Skagit	--	--	--	--	31,713	--	--	8,000
Skamania	--	--	88,120	--	--	2,500	--	--
Snohomish	--	--	--	--	135,762	--	--	11,270
Thurston	--	--	4,904	--	845	--	--	1,580
Wahkiakum	--	--	--	--	--	--	--	--
Whatcom	--	--	--	--	67,246	--	--	--
Total	--	--	365,810	--	246,188	5,250	1,350	296,979
Total Forest	1,600	1,800	467,307	253,872	246,188	320,856	1,350	296,979

t and county, Douglas-fir region, 1966
ner log rule)

sta- nity	Siskiyou	Siuslaw	Six Rivers	Snoqualmie	Umpqua	Wenatchee	Willamette	Winema	Total
--	3,936	--	38,447	--	--	--	--	--	42,383
,490	--	--	136,579	--	--	--	--	--	207,696
060	--	--	--	--	--	--	--	--	247,013
,914	--	--	33,978	--	--	--	--	--	140,892
464	3,936	--	209,004	--	--	--	--	--	637,984
--	--	75,931	--	--	--	--	--	--	75,931
--	3,200	--	--	--	1,600	--	10,250	--	212,983
--	--	--	--	--	--	--	--	--	13,033
--	--	--	--	--	--	--	--	--	19,770
--	68,288	8,221	--	--	--	--	--	--	76,509
--	79,002	--	--	--	--	--	--	--	79,002
--	--	--	--	--	341,440	--	--	--	341,440
--	--	--	--	--	--	--	--	--	89,468
--	--	--	--	--	57,886	--	--	22,237	288,624
--	65,023	--	800	--	--	--	--	--	89,065
--	--	120,691	--	--	52,165	--	588,275	--	762,931
--	--	21,216	--	--	--	--	--	--	21,216
--	--	--	--	--	--	--	158,994	--	159,593
--	--	14,217	--	--	--	--	124,101	--	147,821
--	--	210	--	--	--	--	--	--	88,607
--	--	21,018	--	--	--	--	--	--	21,018
--	--	19,439	--	--	--	--	--	--	19,439
--	--	--	--	--	--	--	--	--	--
--	--	61,235	--	--	--	--	--	--	61,235
--	215,513	342,178	800	--	453,091	--	881,620	22,237	2,567,685
--	--	--	--	--	--	--	--	--	46,592
--	--	--	--	--	--	--	--	--	53,287
--	--	--	--	--	--	--	--	--	52,783
--	--	--	--	--	--	--	--	--	97,707
--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	4,200
--	--	--	--	20,875	--	12,703	--	--	69,784
--	--	--	--	--	--	--	--	--	9,984
--	--	--	--	25,378	--	--	--	--	151,734
--	--	--	--	--	--	--	--	--	101,500
--	--	--	--	--	--	--	--	--	--
--	--	--	--	78,853	--	--	9,000	--	122,875
--	--	--	--	--	--	--	--	--	--
--	--	--	--	10,000	--	--	--	--	49,713
--	--	--	--	--	--	--	--	--	90,620
--	--	--	--	59,773	--	1,200	--	--	208,005
--	--	--	--	10,475	--	--	--	--	17,804
--	--	--	--	--	--	--	--	--	--
--	--	--	--	10,696	--	--	--	--	77,942
--	--	--	--	216,050	--	13,903	9,000	--	1,154,530
464	219,449	342,178	209,804	216,050	453,091	13,903	890,620	22,237	4,360,199

Headquarters for the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is in Portland, Oregon. The Station's mission is to provide the scientific knowledge, technology, and alternatives for management, use, and protection of forest, range, and related environments for present and future generations. The area of research encompasses Alaska, Washington, and Oregon, with some projects including California, Hawaii, the Western States, or the Nation. Project headquarters are at:

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FOREST AND RANGE SOILS RESEARCH IN OREGON AND WASHINGTON

a bibliography with abstracts from 1964 through 1968

APR 6

IC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
DEPARTMENT OF AGRICULTURE · PORTLAND, OREGON
FOREST SERVICE RESEARCH PAPER PNW–90 · 1969

FOREWORD

The purpose of this paper is to reference and briefly summarize all published forest and range soils research done in Oregon and Washington for the past 5 years--1964 to 1968. This paper supplements USDA Forest Service Research Paper PNW-15 published October 1964 showing earlier forest soils research publications. There are some earlier publications listed, as range soils research and theses titles are included for the first time.

The growth of forest and range soils research within Oregon and Washington is quite evident in this paper. In Research Paper PNW-15, 139 publications from the years 1914 through 1963 were listed. In the present paper, 115 new publications are listed for the past 5 years. The talent going into forest and range soils research is emphasized by the 80 theses titles given in this paper.

We have again attempted in the abstracts to accurately brief major findings or the theme of each reference. This condensed information is intended only to lead the reader to the original publication.[1/] A subject matter index is also provided.

An active file of Oregon and Washington forest and range soils research publications is maintained by the author. He would appreciate being notified of any omissions.

[1/] Publications listed herein are not available from the Pacific Northwest Forest and Range Experiment Station unless issued by the organization. Requests for reprints should be addressed to the author cited.

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FOREST AND RANGE SOILS RESEARCH IN OREGON AND WASHINGTON

a bibliography with abstracts from 1964 through 1968

Compiled by
Glen O. Klock, Research Soil Scientist

1969

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
Philip A. Briegleb, Director
Portland, Oregon

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1967. Soil characteristics related to the presence of individual western hemlock and western redcedar trees. Amer. Soc. Agron. Abstr., p. 131.

Soil differences under hemlock and cedar were reflected in the composition of the foliage and surface litter for Ca and pH, but not for N, C, Mg, or K.

2. Anderson, E. William.
1956. Some soil-plant relationships in eastern Oregon. J. Range Manage. 9: 171-175, illus.

From a study of range sites, their soils, original vegetation, and response to grazing use, some significant soil-plant relationships are given.

3. _____
1962. Behavior of forage yields on some range sites in Oregon. J. Range Manage. 15: 245-252, illus.

Discusses some fundamental yield-site-soil relationships that exist on rangelands of eastern Oregon.

4. _____
1968. Soil information for range resource evaluation. J. Range Manage. 21: 406-409, illus.

Discusses the flexibility needed in designing soil mapping units to meet the needs of the range manager.

5. _____ and Poulton, C. E.
1958. Collection of ecological data for soil-site correlation in Oregon. U.S. Soil Conserv. Serv. and Oreg. State Univ. Joint Publication, 17 pp.

6. Anderson, Henry W., and Gessel, Stanley P.
1966. Effects of nursery fertilization on outplanted Douglas-fir. J. Forest. 64: 109-112, illus.

Application of 50 pounds per acre nitrogen in the nursery late in the growing season significantly increased field survival. Fertilized trees grew faster and were taller than unfertilized trees at the end of 5 years.

7. Babalola, O., Boersma, L., and Youngberg, C. T.
1968. Photosynthesis and transpiration of Monterey pine seedlings as a function of soil water suction and soil temperature. Plant Physiol. 43(4): 515-521, illus.

Photosynthesis, respiration, and transpiration rates of Monterey pine were found to decrease with decreasing soil water content and decreasing soil temperature.

8. Balci, A. N.
1968. Soil erosion in relation to properties of eastern and western Washington forest soils. Soil Sci. Soc. Amer. Proc. 32: 430-432.

Soil erodibility and related properties of forest soils sampled from similar parent materials were compared and real differences found.

9. Barrett, James W., and Youngberg, C. T.
1965. Effect of tree spacing and understory vegetation on water use in a pumice soil. Soil Sci. Soc. Amer. Proc. 29: 472-475, illus.

Water use in a pumice soil in central Oregon increased significantly with increased density of a sapling ponderosa pine (*Pinus ponderosa* Laws.) stand.

10. Bollen, Walter B., Chen, Chi-Sin, Lu, Kuo C., and Tarrant, Robert F.
1967. Influence of red alder on fertility of a forest soil--microbial and chemical effects. Oreg. State Univ., Forest Res. Lab. Res. Bull. 12, 61 pp., illus.

Microbial and chemical characteristics of soil under stands of alder, conifer, and mixtures of both were determined at seasonal intervals. Total nitrogen was always higher under alder and the mixed stand than beneath conifers. *Streptomyces*, most prominent under the mixed stands, produce antibiotics which may inhibit fungal pathogens that attack roots of conifers.

11. Bollen, W. B., Chen, C. S., Lu, K. C., and Tarrant, Robert F.
1968. Effect of stemflow precipitation on chemical and microbiological soil properties beneath a single alder tree. *In* Biology of alder, J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.), Northwest Sci.Ass. Fortieth Annu. Meet. Symp. Proc. 1967, pp. 149-156.

Stemflow from a single alder tree had greater concentrations of nitrogen and dissolved solids than throughfall of gross precipitation but did not influence chemical or microbial soil properties at a distance of only 2 feet from the stem.

12. _____ and Lu, K. C.
1968. Nitrogen transformations in soils beneath red alder and conifers. *In* Biology of alder, J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.), Northwest Sci. Ass. Fortieth Annu. Meet., Symp. Proc. 1967, pp. 141-148.

Nitrogen transformations, particularly nitrification, are rapid in soils under coastal Oregon stands of red alder, conifers (Douglas-fir, western hemlock, and Sitka spruce), and mixed stands of alder and conifers. Nitrification is especially rapid in the F layer beneath alder stands despite a very low hydrogen-ion concentration.

13. Borchardt, G. A., Theisen, A. A., and Harward, M. E.
1968. Vesicular pores of pumice by mercury intrusion. Soil Sci. Soc. Amer. Proc. 32: 735-737, illus.

Destructive vesicular pore size distribution curves were obtained for pumice materials from Mount Mazama, Glacier Peak, and Newberry Crater.

14. Chichester, F. W., Youngberg, C. T., and Harward, M. E.
1969. Clay mineralogy of soils formed on Mazama pumice. Soil Sci. Soc. Amer. Proc. 33: 115-120.

Samples of the clay fraction in central Oregon pumice were found to have mineral sites consisting predominantly of X-ray amorphous material in combination with a rather complex group of 2:1 phyllosilicates, gibbsite, feldspars, and quartz. Physical and chemical analyses are given for several Mazama pumice soils.

15. Cochran, P. H.
1968. Can thinning slash cause a nitrogen deficiency in pumice soils of central Oregon? Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-82, 11 pp.

Decomposition of thinning slash deposited on the soil surface and decomposition of roots of cut trees should not adversely affect soil nitrogen available to the remaining trees in the pumice soil region. Incorporation of chipped slash into the soil might cause a temporary nitrogen deficiency which could be prevented by fertilization.

16. _____ Boersma, L., and Youngberg, C. T.
1967. Thermal properties of a pumice soil. Soil Sci. Soc. Amer. Proc. 31: 454-459, illus.

Calculated thermal conductivities of Mount Mazama dacite pumice materials were compared with experimentally measured conductivities and found to be in good agreement. The very low thermal conductivity values found may account for the frequent occurrence of light frost in pumice soils.

17. Cole, D. W.
1967. The forest soil--retention and flow of water. Soc. Amer. Forest. Proc. 1966: 150-154, illus.

The theory of retention and flow of soil water along with experimentally determined values for a forest soil is presented.

18. _____ and Gessel, S. P.
1968. Cedar River research; a program for studying the pathways, rates, and processes of elemental cycling in a forest ecosystem. Inst. Forest Prod. Forest Resources Monogr. 4, 54 pp.

19. _____ and Gessel, Stanley P.
1965. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 95-104, illus.

Only small amounts of N, P, K, and Ca were removed by leaching beyond the effective rooting depth over a 10-month period. Most leaching occurred during the fall and early winter.

20. Cole, Dale W.
1968. A system for measuring conductivity, acidity, and rate of water flow in a forest soil. Water Resources Res. 4: 1127-1136.

An integrated system has been developed for collecting, recording, and analyzing data describing the behavior of water flowing through a forest soil.

21. Corliss, J. F., and Dyrness, C. T.
1965. A detailed soil-vegetation survey of the Alsea Area in the Oregon Coast Range. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 457-483, illus.

This soil-vegetation survey is not only an inventory of the two resources but includes descriptions of the relationships and lists use limitations. It provides land managers with information for evaluating land use alternatives, recognizing potential problems, and formulating management plans.

22. Czamanske, Gerald K., and Porter, Stephen C.
1965. Titanium dioxide in pyroclastic layers from volcanos in the Cascade Range. Science 150: 1022-1025, illus.

Widespread layers of volcanic ash from Glacier Peak and Mount Mazama have characteristic ranges of TiO_2 content that are of value in differentiating the two.

23. De Backer, L. W., and Boersma, L.
1967. Water movement in small forest covered plots. Oreg. State Univ., Water Resources Res. Inst. Progr. Rep.

Methods of measuring and analyzing the water budget in soils under stands of Douglas-fir and oak are presented.

24. Driscoll, Richard S.
1964. Vegetation-soil units in the central Oregon juniper zone. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-19, 60 pp., illus.

A detailed description of vegetation and soil characteristics of the central Oregon juniper zone is presented, including a key to its plant associations and application of the findings to range and wildlife habitat management.

25. Dyrness, C. T.
1965. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. J. Forest. 63: 272-275, illus.

Runoff and erosion from tractor logging and compaction are minimized if slopes do not exceed 20 to 30 percent and skidroads are located on the contour.

26. _____
1966. Erodibility and erosion potential of forest watersheds. Int. Symp. Forest Hydrol., Nat. Sci. Found. Advanced Sci. Seminar Proc. 1965: 599-611.

Discusses factors affecting forest soil erodibility; the influence of fire, logging, and road construction on measured amounts of erosion and soil erodibility characteristics; and research needs in this field.

27. _____
1966. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ecology 47: 122-138, illus.

Six plant communities were identified and characterized. Soils are regosols developed on Aeolian pumice deposits. Soil morphology, moisture depletion rate, and fertility were related to plant community occurrence.

28. _____
1967. Mass soil movements in the H. J. Andrews Experimental Forest. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-42, 12 pp., illus.

A study of 47 mass movement events, resulting from severe storms during the winter of 1964-65, found that 72 percent were connected with road construction and the great majority occurred in soils derived from pyroclastic parent materials.

29. _____
1967. Soil surface conditions following skyline logging. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-55, 8 pp.

A study on the west side of the Cascade Range in Oregon indicated very little difference in yarding-caused soil disturbance between skyline and high-lead logging methods. The main advantage of skyline yarding is that it requires far less road construction than other logging methods.

30. _____
1967. Grass-legume mixtures for roadside soil stabilization. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-71, 19 pp., illus.

Field evaluation of legumes indicated that big trefoil, white Dutch clover, New Zealand white clover, and birdsfoot trefoil grow moderately well on subsoil sites in central Oregon coast ranges and at low elevations in western Cascades. Erosion plot experiments at a typical backslope site in H. J. Andrews Experimental Forest showed four grass-legume seeding mixtures and a straw mulch-fertilizer treatment were equally effective in curtailing soil movement. Bare controls were the only plots showing significant erosion.

31. Franklin, Jerry F., and Pechanec, Anna A.
1968. Comparison of vegetation in adjacent alder, conifer, and mixed alder-conifer communities. I. Understory vegetation and stand structure. *In* Biology of alder, J. M. Trappe, . F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.). Northwest Sci. Ass. Fortieth Annu. Meet. Symp. Proc. 1967: 37-43.

32. _____ Dyrness, C. T., Moore, Duane G., and Tarrant, Robert F.
1968. Chemical soil properties under coastal Oregon stands of alders and conifers. *In* Biology of alder, J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.). Northwest Sci. Ass. Fortieth Annu. Meet. Symp. Proc. 1967: 157-172.

Organic matter, total nitrogen, and acidity were significantly greater in A horizons under alder and mixed stands. A horizons under conifer stands averaged three times richer in bases than those under alder stands. Similar differences, but of a much smaller magnitude, were observed in the B horizons. These effects may indicate greater production of acid decomposition products in the organic- and nitrogen-richer alder soils.

33. Franklin, Jerry Forest.
1966. Vegetation and soils in the subalpine forests of the southern Washington Cascade Range. Diss. Abstr. 27(6)B, 1746-B.

34. Fredriksen, R. L.
1963. Sedimentation after logging road construction in a small western Oregon watershed. Fed. Inter-Agency Sedimentation Conf. Proc. 1963. U.S. Dep. Agr. Misc. Pub. 970: 56-59, illus.

Suspended sediment in undisturbed watersheds follows a cyclic concentration pattern largely influenced by the precipitation and runoff pattern in western Oregon. Slides play an important but unpredictable role in geologic erosion.

35. _____
1965. Christmas storm damage on the H. J. Andrews Experimental Forest. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-29, 11 pp., illus.

Three experimental watersheds in the western Cascades showed erosion from headwater streams occurring by mass movements during rain-snowmelt runoff periods. Erosion sequences in headwater streams and lower order streams are discussed.

36. Gessel, Stanley P., and Balci, A. Nihat.
1965. Amount and composition of forest floors under Washington coniferous forests. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 11-23, illus.

Differences in total depth and weight, humus layer type, weight loss-on-ignition, C:N ratio, chemical properties, and stage of decomposition are discussed for forest floors.

37. _____ and Cole, Dale W.
1965. Influence of removal of forest cover on movement of water and associated elements through soil. J. Amer. Water Works Ass. 57: 1301-1310.

Clearcutting increases the rate of nitrogen release from the forest floor, particularly immediately after cutting. However, this increase in nitrogen movement did not reach a depth of 36 inches in the soil profile.

38. _____ Cole, D. W., and Riekerk, H.
1966. Techniques and preliminary data of the movement of DDT and Zectran through a forest soil. Amer. Soc. Agron. Abstr., p. 94.

Neither DDT, applied to the forest floor at rates of 0.5 and 5.0 pounds per acre, nor Zectran, at 0.01 pound per acre, showed appreciable downward movement over a period of 1 year.

39. _____ Stoate, T. N., and Turnbull, K. J.
1965. The growth behavior of Douglas-fir with nitrogenous fertilizer in western Washington - a first report. Univ. of Wash., Coll. of Forest. Res. Bull. No. 1, 204 pp., illus.

According to measurements of 238 field plots made to determine the effects of using fertilizer on growth of Douglas-fir, nitrogen is the one growth-stimulating nutrient element thus far noted.

40. Gehrke, F. E., and Steinbrenner, E. C.
1965. Soil survey methods used in mapping Weyerhaeuser Company forest lands in the Pacific Northwest. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 485-494, illus.

Weyerhaeuser Company has a detailed and accurate inventory of soils on 888,000 acres of its tree-farm lands for use in inventory, research, and forest management planning.

41. Gould, Marie L.
1965. Soil moisture investigations on grass- and shrub-land soils, 1942-1964; a bibliography. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 5 pp.

42. Hallin, William E.
1967. Soil-moisture and temperature trends in cutover and adjacent old-growth Douglas-fir timber. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-56, 11 pp., illus.

Seasonal trends in soil moisture were compared for a timbered area and adjoining cutover area. Soil moisture on the cutover area was similar to that on the timbered area, indicating a nearly equal moisture drain by lesser vegetation on the cutover area.

43. _____
1968. Soil surface temperatures on cutovers in southwest Oregon. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-78, 17 pp., illus.

Expected soil temperatures on various microsites and macrosites are presented, as well as recommendations for harvest techniques on steep southerly slopes.

44. Hermann, R. K.
1967. Paper mulch helps ponderosa pine seedlings get started on dry sites in Oregon. Tree Planters' Notes 18(4): 14-15.

Use of an asphalt-interlined paper mulch on 2-0 ponderosa pine seedlings significantly increased their rate of survival.

45. Hermann, Richard K.
1968. A watering experiment with sown ponderosa pine in central Oregon. Northwest Sci. 42: 47-52, illus.

46. Herring, H. G.
1968. Soil-moisture depletion by a central Washington lodgepole pine stand. Northwest Sci. 42: 1-4, illus.

Soil moisture under a lodgepole pine stand was measured at biweekly intervals throughout the growing season for 4 consecutive years. Data are presented on the summer soil moisture regime both before and after the trees were removed.

47. Hinds, W. T., and Rickard, W. H.
1968. Soil temperature near a desert steppe shrub. Northwest Sci. 42(1): 5-13, illus.

48. Hu, L., Youngberg, C. T., and Gilmour, C. M.
1968. Soluble carbon and respiration of forest humus. Amer. Soc. Agron. Abstr., p. 136.

Water soluble carbon determinations were shown to serve as a good index of stage of decomposition and humification of forest floor materials due to the positive correlation between water soluble carbon contents and respiration rates.

49. Klomp, G. J.
1968. The use of woodchips and nitrogen fertilizer in seeding scab ridges. J. Range Manage. 21: 31-36, illus.

Good initial stands of a timothy, hard fescue, and pubescent wheatgrass mixture were obtained from use of woodchips and nitrogen on scab ridges of northeastern Oregon.

50. Knox, E. G., Corliss, J. F., and Williams, J. M.
1965. Dark colored, acid, forest soils of western Oregon. Soil Sci. Soc. Amer. Proc. 29: 732-736, illus.

Describes properties of well-drained, strongly leached, relatively dark-colored soils of the most humid, forested areas of western Oregon and Washington. These soils are Haplumbrepts according to the 7th Approximation.

51. Kubota, Joe, Simonson, Victor A., and Hill, W. W.
1967. The relationship of soils to molybdenum toxicity in grazing animals in Oregon. Soil Sci. Soc. Amer. Proc. 31: 667-671, illus.

Molybdenum toxicity in ruminant animals has been traced to a soil-related nutritional problem.

52. Kuhlman, E. George.
1964. Survival and pathogenicity of *Phytophthora cinnamomi* in several western Oregon soils. Forest Sci. 10: 151-158.

When moisture is adequate, soil temperature is the critical factor regulating infection of forest trees by *P. cinnamomi* in the Pacific Northwest.

53. LaRock, R. G., and Cole, D. W.
1966. Soil moisture content, flow, tension, and hysteresis in a coarse glacial soil. Amer. Soc. Agron. Abstr., p. 97.

Soil moisture characteristics of a glacial outwash soil were evaluated during periods of soil moisture flow.

54. Li, C. Y., Lu, K. C., Trappe, J. M., and Bollen, W. B.
1967. Effect of pH and temperature on growth of *Poria weirii* in vitro. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-66, 6 pp., illus.

Growth of an isolate, tested on synthetic media ranging from pH 3.0 to 7.5, increased with pH to an optimum at 6.0. No growth occurred at 6.5 or higher. Growth also increased with temperature from 5° C. to 20° C., above which it decreased to none at 30° or higher.

55. _____ Lu, K. C., Trappe, J. M., and Bollen, W. B.
1967. Selective nitrogen assimilation by *Poria weirii*. Nature (London) 213(5078): 814.

This root-rotting fungus cannot assimilate the nitrate form of nitrogen, whereas soil organisms that inhibit *P. weirii* can. A buildup of soil nitrogen, such as occurs from nitrogen fixing by alder nodules, offers potential biological control of the disease.

56. Lopushinsky, William.
1966. Transpiration of conifer seedlings in relation to soil moisture stress. (Abstr.) Plant Physiol. Proc. Annu. Meet. 1966, p. iv.

Transpiration rates of potted ponderosa pine, lodgepole pine, Douglas-fir, grand fir, Engelmann spruce, and western larch seedlings were compared at various levels of soil moisture stress under controlled environmental conditions. Studies of stomatal sensitivity to leaf moisture stress were also made on twigs of each of these species.

57. Lu, K. C.
1968. Effect of organic amendments on soil microflora in relation to fusarium root rot of ponderosa pine seedlings. West. Forest. Conserv. Ass., West. Forest Nursery Counc. Proc. 1968: 40-45, illus.

Microbial populations in all amended plots were significantly higher than those of the control plot, possibly accounting for the reduction in disease associated with amendment.

58. _____Chen, C. S., and Bollen, W. B.
1968. Comparison of microbial populations between red alder and conifer soils. *In* Biology of alder, J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.). Northwest Sci. Ass. Fortieth Annu. Meet. Symp. Proc. 1967: 173-178, illus.

All organisms were generally more numerous in the F layer than in the A_{11} horizon. Populations of molds were lowest in spring, when the soil was extremely wet. In the F layer, *Streptomyces* species, possible antagonists of root pathogens, consistently comprised a higher proportion of the total bacterial population of the mixed stand than of either pure alder or pure conifer stands.

59. Mayland, H. F.
1968. Measuring and interpreting rangeland soil fertility. Amer. Soc. Agron. Abstr., p. 137.

Fertility and potential yield increase indexes were determined for 119 semiarid rangeland soils of southeastern Oregon.

60. McCall, J. G., and Cole, D. W.
1968. A mechanism of cation transport in a forest soil. Northwest Sci. 42: 134-140.

Discusses the mechanisms that play a significant role in the transport and leaching of cations in a forest soil.

61. Miner, Norman H.
1968. Natural filtering of suspended soil by a stream at low flow. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-88, 4 pp., illus.

The "filtering" action occurring in a stream after soil is added by road construction is a combination of settling of larger particles and dilution of sediment-laden water.

62. Neal, J. L., Jr., Bollen, W. B., and Lu, K. C.
1965. Influence of particle size on decomposition of red alder and Douglas-fir sawdust in soil. Nature (London) 205: 991-993, illus.

Influence of sawdust added to soil on microbial activity depends on particle size: the smaller the particle, the faster its oxidation. This relationship may be due to the smaller particle's larger surface area in

relation to volume and the greater rupturing of lignin-cellulose bonds during their mechanical preparation. Addition of ammonium nitrate to sawdust did not stimulate oxygen uptake of samples, perhaps because the addition relieved microbes from the necessity of decomposing nitrogenous organic matter to meet their nitrogen requirements.

63. _____ Bollen, W. B., and Zak, B.
1964. Rhizosphere microflora associated with mycorrhizae of Douglas-fir. Can. J. Microbiol. 10: 259-265, illus.

Rhizosphere populations of mycorrhizal roots differed according to morphological and physiological types and in total numbers compared with suberized root rhizosphere, nonrhizosphere microflora, and kind of mycorrhizal fungi.

64. _____ Lu, K. C., Bollen, W. B., and Trappe, J. M.
1966. Two simple time-saving techniques for studies of soil microbial populations and subsequent culture characterization. Int. Soc. Soil Sci. Comm. III News Bull. 6: 38.

Through use of these low-cost materials and two simple techniques, microbial populations can be estimated and colonies isolated with substantial savings in time.

65. _____ Lu, K. C., Bollen, W. B., and Trappe, J. M.
1967. Two simple, time-saving techniques for studies of soil micro-organisms. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-57, 3 pp., illus.

Methods are described for uniform inoculation of an agar surface in a petri plate with a diluted soil suspension and for transfer of resulting colonies to sterile, broth-containing culture tubes.

66. _____ Lu, K. C., Bollen, W. B., and Trappe, J. M.
1968. A comparison of rhizosphere microfloras associated with mycorrhizae of red alder and Douglas-fir. *In* Biology of alder, J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen (eds.). Northwest Sci. Ass. Fortieth Annu. Meet. Symp. Proc. 1967: 57-71, illus.

Microbial populations and ammonifying and nitrate-reducing microbes differed quantitatively and qualitatively between two microhabitats. Respiration of nonrhizosphere microbes was stimulated by Douglas-fir nonmycorrhizal root and red alder mycorrhizal root suspensions. Apparently an inhibitory substance in Douglas-fir mycorrhizal roots and red alder nonmycorrhizal roots suppressed glucose oxidation.

67. _____ Lu, K. C., Trappe, J. M., and Bollen, W. B.
1966. Rhizosphere microbial activity of mycorrhizal and nonmycorrhizal roots of Douglas-fir and red alder. (Abstr.) Amer. Soc. Microbiol. Bacteriol. Proc. 1966, 2, A10.

Micro-organisms were more abundant on root surfaces of alder than of Douglas-fir. Different kinds of mycorrhizae varied in surface populations as well. Such differences may strongly influence the susceptibility of roots to attack by disease fungi.

68. Neal, John L., Wright, Ernest, and Bollen, Walter B.
1965. Burning Douglas-fir slash: physical, chemical, and microbial effects in the soil. Oreg. State Univ., Forest Res. Lab. Res. Pap. 1, 32 pp.

Initial effects of slash burning on physico-chemical and microbiological properties of soil appeared beneficial to soil fertility, but over a period of 1 year apparently lessened in desirability.

69. Norris, Logan A.
1968. Recovery of amitrole from forest litter. *In* Research progress report. West. Soc. Weed Sci., pp. 31-32.

The amount of amitrole herbicide recoverable from forest floor material decreases rapidly the first 5 days after the chemical is applied. Such loss may be due to chemical degradation, complexing with metal ions, adsorption, or any combination of these three actions.

70. Orr, Thomas J.
1965. Some uses, abuses, and potential uses of the soil-vegetation concept. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 495-501.

The soil-vegetation survey is a beginning point for ecological studies, rather than an ultimate answer.

71. Parsons, R. B., and Balster, C. A.
1966. Morphology and genesis of six "Red Hill" soils in the Oregon Coast Range. Soil Sci. Soc. Amer. Proc. 30: 90-93, illus.

Distribution of six soils on a basalt landscape is attributed to the slope gradients of several geomorphic surfaces. Textural discontinuities and soil chemical data are shown to be related to the geomorphology of the area.

72. Poulton, C. E.
1959. Soil-vegetation research and surveys in multiple-use management of western ranges. *In* Amer. Ass. Advance. Sci., Grasslands Proc., pp. 359-370.

73. Radwan, M. A.
1965. Persistence and effect of TMTD on soil respiration and nitrification in two nursery soils. Forest Sci. 11: 152-159, illus.

The persistence of tetramethylthiuram disulfide and some of its effects in the soil are examined with relation to its use as a repellent in forest tree nurseries.

74. Reukema, Donald L.
1964. Litter fall in a young Douglas-fir stand as influenced by thinning. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-14, 8 pp., illus.

A 13-year record from a young Douglas-fir stand illustrates the effect on amount and timing of litterfall by thinning treatments and climatic variations.

75. _____
1968. Growth response of 35-year-old, site V Douglas-fir to nitrogen fertilizer. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-86, 9 pp., illus.

During the first 4 years following application, addition of 200 to 600 pounds of nitrogen per acre increased tree growth substantially. However, because heavier applications also increased amount of snowbreakage, net production tended to be greatest with the addition of 200 pounds per acre.

76. Riekerk, H.
1968. The mobility of phosphorus, potassium, and calcium in a forest soil. Amer. Soc. Agron. Abstr., p. 138.

Results of a study indicate that nutrient mobility is dependent on the ionic properties and biological functions of the elements, as well as the chemical and hydrothermal properties of forest soil components.

77. _____ and Gessel, S. P.
1965. Mineral cycling in a Douglas-fir forest. Health Phys. (Oxford) 11: 1363-1369, illus.

In a 40-year stand of Douglas-fir on gravelly, sandy loam the forest floor was treated with P^{32}, Rb^{86}, and Ca^{45}. Observations with tension lysimeters indicated a significant leaching of P^{32}.

78. _____ and Gessel, S. P.
1968. The movement of DDT in forest soil solutions. Soil Sci. Soc. Amer. Proc. 32: 595-596.

Periodic leachate collections from tension lysimeters placed under the forest floor and surface soil upon which DDT had been sprayed were analyzed. The sensitivity of the measurement techniques is demonstrated by the trace levels of DDT detected.

79. Rothacher, J., Dyrness, C. T., and Fredriksen, R. L.
1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 54 pp., illus.

Trapezoidal flumes and other instrumentation were used to gather data preliminary to a study of the effect of timber harvesting and road construction on yield, timing, and quality of streamflow from three tributary watersheds in the McKenzie drainage of western Oregon. During the calibration period when the dense Douglas-fir forests remained undisturbed, data were collected which described the relationship of geology, soils, vegetation, and climate to streamflow.

80. Russel, Sterling A., and Evans, Harold J.
1966. The nitrogen fixing capacity of *Ceanothus velutinus*. Forest Sci. 12: 164-169, illus.

The efficiency of N fixation and the amount of N fixed per growth season for *Ceanothus velutinus* were found to be of the same order of magnitude as that reported for several legumes and nonleguminus symbionts.

81. Sauerwein, William J.
1965. Developing soil survey interpretations with a large forest landowner. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 441-455, illus.

Illustrates the development of soil-woodland interpretations from soil surveys of a 50,000-acre private forest.

82. Steen, Virginia C., and Fryxell, Roald.
1965. Mazama and Glacier Peak pumice glass: uniformity of refractive index after weathering. Science 150(3698): 878-880, illus.

Weathering has had little differential effect on modal values of the index of refraction of pumice glasses from the eruptions of Mount Mazama and Glacier Peak thousands of years ago. Confidence is thus increased that the ranges of values are reliable for distinguishing the two glasses.

83. Steinbrenner, E. C.
1965. The influence of individual soil and physiographic factors on the site index of Douglas-fir in western Washington. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 261-277, illus.

Soil and physiographic factors having either a positive or negative effect on growth of Douglas-fir are indicated.

84. _____ and Rediske, J. H.
1964. Growth of ponderosa pine and Douglas-fir in a controlled environment. Weyerhaeuser Co., Forest. Pap. 1, 31 pp., illus.

This study assesses the growth response of ponderosa pine and Douglas-fir seedlings to controlled high and low levels of soil moisture, nitrogen, root temperature, air temperature, relative humidity, and light.

85. Stephens, F. R.
1965. Ponderosa pine thrives on wet soils in southwestern Oregon. J. Forest. 63(2): 122-123, illus.

In the South Umpqua drainage, growth of ponderosa pine on imperfectly drained soils is better than that of associated Douglas-fir and sugar pine. Ponderosa pine does not grow here on shallow, stony soils, although Douglas-fir, sugar pine, and other conifers form commercial stands.

86. _____
1965. Relation of Douglas-fir productivity to some zonal soils in the Northwestern Cascades of Oregon. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 245-260, illus.

Despite a wide range in physiography and productivity, the soil series taxonomic unit is considered to predict Douglas-fir site index accurately on soils mapped in six well-drained zonal soils of the Oregon Cascades.

87. _____
1966. Lodgepole pine--soil relations in the Northwest Oregon Cascade Mountains. J. Forest. 64: 184-186, illus.

In the study area, lodgepole pine grows only on well and excessively well drained, moderately coarse- and coarse-textured soils; and on poorly and very poorly drained organic soils.

88. Strand, R. F., and Austin, R. C.
1966. Evaluating fertilizer and other materials to speed growth of planted Douglas-fir. J. Forest. 64: 739-744, illus.

Several fertilizers, including magnesium ammonium phosphate, coated diammonium phosphate, and Torula yeast, are compared with two forms of urea with respect to release of nitrogen and increase of seedling growth.

89. Strickler, Gerald S.
1966. Soil and vegetation on the Starkey Experimental Forest and Range. Soc. Amer. Forest. Proc. 1965: 27-30.

Three forest and six grassland soil series are described and the vegetation characteristics of each discussed. Application to range research and management programs is given.

90. Tarrant, R. F.
1968. Forest soil improvement through growing red alder (*Alnus rubra* Bong.) in Pacific Northwestern United States. Eighth Int. Congr. Soil Sci. Trans., Bucharest, 1964. V: 1029-1043.

Compared with other species of *Alnus* studied throughout the Northern Hemisphere, red alder is at least equally effective in improving soil fertility and growth of associated trees. Silvicultural application of soil-improving and tree-growth-promoting qualities of red alder is considered feasible and desirable.

91. _____ Lu, K. C., Bollen, W. B., and Chen, C. S.
1967. Chemical composition of throughfall and stemflow in three coastal Oregon forest types. Amer. Soc. Agron. Abstr., p. 137.

92. _____ Lu, K. C., Bollen, W. B., and Chen, C. S.
1968. Nutrient cycling by throughfall and stemflow precipitation in three coastal Oregon forest types. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-54, 7 pp.

Throughfall and stemflow were collected beneath three adjacent forest types--red alder, conifer (Douglas-fir, western hemlock, and Sitka spruce), and a mixture of alder and conifer. Weight of N and dissolved solids in stemflow was insignificant because of small amounts of stemflow and soil area affected. Nutrient cycling rates differ appreciably among the three forest types.

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In pure stands or as an admixture with conifers, red alder has about a threefold increase in the amount of N circulating in litterfall and precipitation.

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1966. Growth and nutrient uptake of irrigated young ponderosa pine after fertilizer treatments. Soil Sci. Soc. Amer. Proc. 30: 796-799, illus.

Growth of irrigated ponderosa pine increased as amount of nitrogen fertilizer was increased. Phosphorus fertilizer in combination with nitrogen either increased or decreased growth depending on rates used. Unfertilized but irrigated trees grew much faster than unirrigated trees nearby.

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1965. Tuberculate mycorrhizae of Douglas-fir. Forest Sci. 11: 27-32, illus.

Describes formation and method of spreading in soil of a mycorrhiza, formed by two fungi in combination, which commonly occurs on Douglas-fir in the western coastal states and British Columbia.

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1966. Effect of fertilizer application on the color and growth of Douglas-fir Christmas trees. West. Soc. Soil Sci. Abstr. 1966: p. 21.

Describes effects on color, growth, and cone production of applying N, P, K, S, and Mg to chlorotic 15-year-old trees.

97. Turner, Darrell O.
1966. Color and growth of Douglas-fir Christmas trees as affected by fertilizer application. Soil Sci. Soc. Amer. Proc. 30: 792-795.

Improved foliage color, with no effect on growth during the first season, was demonstrated with the proper timing of nitrogen applications. Foliage color was correlated to needle nitrogen concentration, thus making possible the use of foliar analyses for scheduled fertilizer treatments.

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1967. Influence of fertilizer treatment on growth and disease escape of salal (*Gaultheria shallon*). Amer. Soc. Agron. Abstr., p. 137.

Use of nitrogen fertilization on salal accelerated growth rates, which in turn brought plant development ahead of the peak period of fungi sporulation.

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1967. Fixation of nitrogen by bitterbrush (*Purshia tridentata* (Pursh) DC.). Nature (London) 216(5113): 392-393, illus.

Results of a study imply that bitterbrush makes a significant contribution to the nitrogen economy of the ecosystem in which it occurs.

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1967. Some characteristics of forest floors and soils under true fir-hemlock stands in the Cascade Range. Pacific Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-37, 19 pp., illus.

Forest floors under 46 true fir-hemlock stands are discussed, using such characteristics as depth and weight of forest floor material, humus type, and amounts of available plant nutrients in the forest floor.

101. Wilson, A. M., Harris, G. A., and Gates, D. H.
1966. Fertilization of mixed cheatgrass-bluebunch wheatgrass stands. J. Range Manage. 19: 134-137.

Range sites having dense bluebunch wheatgrass and sparse cheatgrass or sparse bluebunch wheatgrass and dense cheatgrass were fertilized with increasing amounts of ammonium sulfate. Rather than improving range, heavy fertilization (80 pounds N per acre in 4 consecutive years) produced a retrogression in range condition: bluebunch wheatgrass yields decreased 50 percent and cheatgrass increased 400 to 600 percent.

102. Witty, John E., and Knox, Ellis G.
1964. Grass opal in some chestnut and forested soils in North Central Oregon. Soil Sci. Soc. Amer. Proc. 28: 685-688, illus.

The practicality of using grass opal as an indicator of the vegetative history of soils was investigated in a forest-grassland transition.

103. Wollum, A. G., II.
1966. Effects of soil temperature and light intensity on snowbrush. Amer. Soc. Agron. Abstr., p. 97.

Ceanothus velutinus was germinated and grown under several soil temperatures and light intensities. Optimum nodulation occurred between 20° and 25° C., and the results suggest that photosynthesis is required.

104. _____ and Youngberg, C. T.
1964. The influence of nitrogen fixation by nonleguminous woody plants on the growth of pine seedlings. J. Forest. 62(5): 316-321, illus.

Snowbrush and red alder seedlings fixed nitrogen which became available for growth of Monterey pine seedlings within a limited mass of low-nitrogen soil. Amount of nitrogen fixed by snowbrush was about twice that provided by red alder.

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1966. Characterization of a *Streptomyces* sp. isolated from root nodules of *Ceanothus velutinus* Dougl. Soil Sci. Soc. Amer. Proc. 30(4): 463-467, illus.

A total of 136 similar *Streptomyces* spp. were isolated from nodules of *Ceanothus velutinus*. Characterization by standard bacteriological procedures suggested that the isolates belonged to a single species, which did not correspond to any previously recognized *Streptomyces* sp.

106. Wooldridge, David D.
1964. Effects of parent material and vegetation on properties related to soil erosion in central Washington. Soil Sci. Soc. Amer. Proc. 28: 430-432.

Soil properties are influenced directly by parent material type and horizon development and indirectly by forest and grass vegetation. Soil erosion hazard is apparently related to soil organic matter, pH, total soil porosity, and bulk density.

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1965. Soil properties related to erosion of wild-land soils in central Washington. *In* Forest-soil relationships in North America. Second N. Amer. Forest Soils Conf. Proc. 1963: 141-152, illus.

Describes a two-phase investigation of the relationship of soil properties to an index of soil erosion, mean aggregate size.

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Rates and patterns of actual soil particle movement were established by measuring changes in radiation intensity with time on an eroding sandstone soil.

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1967. Water transport in soils and streams. *In* Transport phenomena in atmospheric and ecological systems. Amer. Soc. Mech. Eng. Proc. 1967: 3-20, illus.

Theory and concepts of moisture retention and flow in soils are reviewed and related to soil properties and subsequent contributions to streamflow. Water in streams is discussed in relation to climate, and forested areas as a source of streamflow are emphasized.

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1968. An air pycnometer for forest and range soils. USDA Forest Serv. Pacific Northwest Forest & Range Exp. Sta., 11 pp., illus.

The calibration and use of an air pycnometer for accurately assessing porosity of forest and range soils are described.

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1968. Forest floor and surface soils properties in central Washington. Amer. Soc. Agron. Abstr., p. 140.

Organic matter, pH, and exchangeable and total chemical analyses are presented for the L, F, and H layers of the forest floor and the soil A_1 horizon from a number of locations.

112. _____ and Gessel, S. P.
1966. Forests and the Nation's water. Amer. Water Resources Ass., Water Resources Bull. 2: 7-12.

Forest lands are the source of three-quarters of the Nation's total usable streamflow. Increasing demands for use of forested acres for many forms of outdoor recreation and increasing demands for the forest's raw materials pose varied problems to resource managers. Activities on forest lands can alter the quality and quantity of water yielded.

113. Youngberg, C. T.
1966. Forest floors in Douglas-fir forests. I. Dry weight and chemical properties. Soil Sci. Soc. Amer. Proc. 30: 406-409.

Douglas-fir stands having different types of understory vegetation had dry weight and volatile matter of forest floors ranging from 20,000 to 76,000 pounds per acre and from 69 to 86 percent. Total N ranged from 0.71 to 1.52 percent. Values for other elements, exchangeable cations, and cation-exchange capacities are given.

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1968. Effects of fertilization and thinning on the growth of ponderosa pine. Amer. Soc. Agron. Abstr., p. 140.

Growth was found to be 90 percent greater after thinning and 160 percent greater after thinning and fertilization than in the untreated stand.

115. _____ and Dyrness, C. T.
1965. Biological assay of pumice soil fertility. Soil Sci. Soc. Amer. Proc. 29: 182-187, illus.

The fertility of pumice soils is difficult to assess by laboratory analysis. A biological assay of growth responses, utilizing a composite experimental design with ponderosa pine as indicator species, yields more meaningful information.

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1962. The effects of nursery fertilization on the growth of Douglas-fir. Univ. Wash.

119. André, Johnnie Edgar.
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